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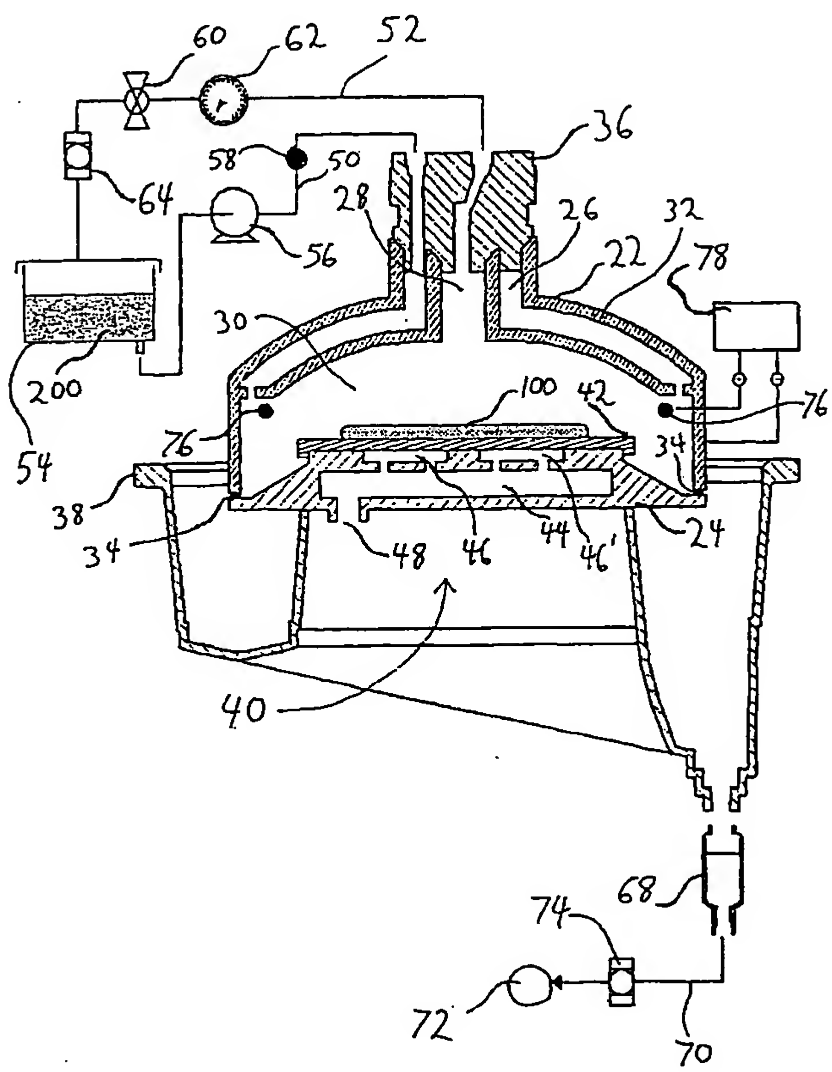
(54) Title: PLATING APPARATUS AND METHOD



(57) Abstract: The present invention comprises a metal plating apparatus and method, particularly suitable for autocatalytic (i.e.. electroless) plating, comprising a pressurized sealable vessel for disposing a substrate to be plated and for the circulation of plating solutions wherein temperatures and pressure are highly controllable.

WO 2005/076977 A2

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PLATING APPARATUS AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of the filing of U.S. Provisional Patent Application Serial No. 60/541,687, entitled "Pressurized Autocatalytic Vessel and Vacuum Chuck", filed February 4, 2004. This application is also related to U.S. Patent Application No. 10/778,647, entitled "Apparatus and Method for Highly Controlled Electrodeposition", filed February 12, 2004, which claims priority of U.S. Provisional Patent Application Serial No. 60/447,175, entitled "Electrochemical Devices and Processes", filed February 12, 2003, and which is a continuation-in-part application of U.S. Patent Application No. 10/728,636, entitled "Coated and Magnetic Particles and Applications Thereof", filed December 5, 2003, which claims priority of U.S. Provisional Patent Application Serial No. 60/431,315, entitled "Solid Core Solder Particles for Printable Solder Paste", filed on December 5, 2002, and the specifications and claims thereof are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention (Technical Field):

The present invention relates to the plating of substrates via metal deposition. Such plating involves either electrolytic plating or electroless plating, otherwise commonly referred to as autocatalytic plating.

Background Art:

During a typical autocatalytic plating process, catalytically induced chemical reactions cause the continuous deposition of a metal onto a solid surface. Autocatalytic plating reactions are driven primarily by the temperature of the reaction, and secondarily by the solution pH and the relative concentrations of the metal complexes and their corresponding reducing agents. Typically, the substrate surface is prepared for electroless

deposition by making it cathodic relative to the metal species to be deposited to create a continuous surface layer of initiation sites for the redox reactions.

Note that the following discussion refers to a number of publications and references. Discussion of such publications herein is given for more complete background of the scientific principles and is not to be construed as an admission that such publications are prior art for patentability determination purposes.

Electroless plating has been used for electronic assembly components. There is now a significant interest in using it for plating silicon wafers and other wafer scale and semi-conductor devices. However, it is difficult to control spurious and extraneous metal deposition onto surface areas where the metal is not desired. Because autocatalytic plating is governed by the chemical activity of the surface exposed to the plating solution as well as by the chemical activity of the plating solution, metal often deposits wherever and whenever a suitably activated surface and a plating solution of sufficient chemical activity come in contact.

Deposit edge resolution is not a primary concern with regard to large coverage areas, but it is of greater concern with regard to the plating of semiconductor wafers and substrates at micron feature line widths. At micron and submicron feature sizes, the magnitude of plating resolution and definition errors can approach, and even exceed, the feature separation distance. This can cause conductor bridging and electrical shorting of the wafer or substrate.

In conventional practice, the propensity for electroless plating chemical solutions to deposit metal indiscriminately is controlled by incorporating any number of chemical rate inhibitors. The inhibitors raise the chemical activation threshold for the reduction of the metal ions out of solution thereby limiting their deposition to only well activated surfaces. However, the addition of inhibitors can negatively impact the utility of plating for subsequent joining/connecting procedures. For example, a residue of incorporated organics on, or within, the plating deposit can preclude solder wetting or wire bonding to that metal surface.

This effect has discouraged the wide use of conventional electroless plating technology for wafer scale electronic joining applications.

Electroless plating is conventionally done in an open vessel or tank. The vessel is typically made of either plastic or of plastic lined metal to prevent the electroless chemicals from spontaneously depositing out of solution when the plating solution comes in contact with a metal surface.

A plastic, glass or polytetrafluoroethylene ("PTFE") coated immersion heater is typically used to maintain the bath at the optimal process temperature, which may range from 35 to 85 degrees Celsius. The bath is typically mixed by stirring or by pumping the solution in the tank.

The substrate is typically prepared by first immersing it in a chemical cleaning solution followed by a rinse and an immersion in a catalytic activator solution. The activated substrate is then immersed in the hot plating bath until the desired thickness of the plating layer is built up. The item is then removed, rinsed again, and dried.

The following example outlines a typical process flow for conventional electroless plating as it is conventionally practiced in multiple tanks for an Electroless Nickel Immersion Gold ("ENIG") process:

1. immersion in an aluminum cleaner;
2. immersion in a zincate activation solution;
3. immersion in a desmut or strip solution;
4. immersion in a second zincate solution;
5. rinse in deionized water;
6. immersion in a heated nickel electroless plating bath solution;
7. multiple rinses (1-3 times) in deionized water;
8. immersion in an immersion gold bath solution; and
9. rinse in deionized water.

This process is conventionally practiced in a serial arrangement of open tanks, with the wafers or substrates fixed in a plastic or plastic coated rack or wafer carrier. The wafers or substrates are manually moved in their carrier from tank to tank or are conveyed by a mechanical transporter. The requirement to physically move the wafer or substrate from tank to tank creates a significant risk of damage to the wafer. The risk of damage is increased by the ongoing trend in the semiconductor processing industry to "thin" wafers by chemical or mechanical means, making an already delicate structure even more fragile.

To function well, conventional electroless plating deposition processes require an optimum bath volume to plated work surface area loading ratio. Therefore, a serial bath, open tank electroless plating line, once constructed, will function well only within a fairly narrow range of work volumes and area ratios.

Therefore, there is a need to better adapt autocatalytic plating techniques and processes for optimal application in the semiconductor industry.

With respect to the electrolytic plating of thin wafers such as those found in the semiconductor industry, the existing electrolytic plating methodology suffers from certain limitations. To plate a wafer, the wafer is typically fixed onto a rigid substrate to allow for plating, and an array of metallic contacts are electrically connected via a wire to a direct current power supply and to a counter-electrode (i.e. the anode). The metallic surfaces of contacts must be completely isolated so that deposits are not allowed to build up around the contact. Such build-up detrimentally fuses the contact point to the surface of the wafer and at the completion of the process can result in a tearing or removal of the deposited film at the contact point.

Another limitation of electrolytic plating is that the resulting surface area of the exposed contact can greatly affect the amperage density applied and the cathode efficiency of the wafer, which must be strictly controlled. This causes inaccurate or inconsistent

results in the mean target thickness of the deposited film. Also, the contacts are a source of impurities that can be introduced onto the wafer.

Electrolytic plating requires that a radial array of contacts be disposed around the periphery of the wafer to be plated. A current is bussed in through the wafer's edge where the array is disposed. The higher the number of contact points around the periphery of the wafer, the better the distribution of current. The existing designs for electrolytic plating require a chemical contact point and therefore create limitations in the number of contact points that can be supplied around the periphery and effectively sealed to prevent a detrimental influence on the surface area of the plated wafer.

A limitation of copper electro-deposition on silicone wafers is that the copper electrolyte and the resulting copper deposit can contaminate the silicon. This converts the semiconductor material into a conductive material, thereby ruining the entire wafer by converting the surface from insulator to conductor.

Currently, the semiconductor industry favors the "damascene" process for depositing copper, and techniques for depositing the copper patterns have progressively favored the electrolytic deposition of the metal. A number of clamping or sealing mechanisms have been devised to seal off the edges and back side of the wafer thereby exposing, through a circular or other patterned window, the surface to be plated. Such devices are fairly complicated in that typically a sandwich comprising a back plate, an O-ring seal, and a top frame must be clamped, bolted, or fixed to the wafer. This limits the effectiveness of automating the wafer handling process in a production environment.

Consequently, the complicated nature of such devices limits the cross-sectional area of the bussing elements which connect to the contact points. The resulting buss cross-section is reduced to favor the mechanical design, which detrimentally affects impacity or current carrying capacity. This causes the requirement for a higher voltage to complete the current flow through the fixture.

A better, more effective method or apparatus for holding a substrate during plating and for sealing portions of the substrate and electrical contacts is required.

BRIEF SUMMARY OF THE INVENTION

The present invention comprises a plating apparatus comprising a pressurized, sealable vessel within which to dispose a substrate during plating of the substrate, a controllable source of a plating fluid linked to the vessel, a holding apparatus to secure the substrate within the vessel until the plating of the substrate is complete, and at least one opening through which plating fluids pass in and out of the vessel. In the preferred embodiment, the apparatus is particularly applicable to autocatalytic plating.

The invention is particularly suitable to plating semiconductor wafers.

The apparatus preferably comprises a closed loop system between the controllable source of plating fluid and the vessel. The invention preferably comprises a pressure control system to control isostatic pressure within the vessel. The controllable source of plating fluids preferably comprises a system for the discreet, sequential introduction and removal of fluids into and from the vessel and preferably comprises a plurality of nozzles and conduits. The at least one opening in the vessel preferably comprises a port.

The apparatus preferably comprises a temperature control system, the system preferably controlling a temperature to within approximately +/- 1 ºC. The temperature control system preferably heats and cools the plating fluid at a rate faster than approximately 0.5 ºC per second, more preferably at a rate faster than approximately 1.0 ºC per second, and most preferably at a rate faster than approximately 2.5 ºC per second. The temperature control system may be disposed outside of the vessel to affect a temperature of a fluid prior to it entering the vessel and/or disposed over the vessel and/or disposed in the vessel. The temperature control system may also be disposed in at least one wall of the vessel.

The vessel preferably comprises a volume of less than less than approximately 5 liters, more preferably less than approximately 3 liters, still more preferably less than approximately 2 liters, still more preferably less than less than approximately 1 liter, and most preferably less than approximately 0.5 liter.

The apparatus preferably comprises a baffle system disposed within the vessel. The apparatus preferably comprises a cathode disposed in the vessel to receive an electric current into the vessel.

The vessel preferably comprises a base plate and a cover to dispose on the base plate. The holding apparatus preferably comprises a vacuum chuck which preferably a base and at least one vacuum cavity in the base. The apparatus preferably comprises at least one membrane disposed over the cavity(ies). The membrane preferably comprises a membrane that is deformable in response to a vacuum, and preferably comprises an elastomeric membrane.

The vacuum chuck preferably comprises a center shuttle disposed in the base. The vacuum chuck also preferably comprises an edge seal boot disposed on the base, and the edge seal boot preferably comprises an edge skirt to contact the substrate and seal a portion of the substrate. The apparatus may comprise an electric bridge contact disposed in the edge skirt, and the contact preferably comprises an array of contacts.

The present invention also comprises a method for depositing metal on a substrate comprising providing a pressurized, sealable vessel, securing the substrate within the sealable vessel, introducing at least one plating fluid into the vessel, removing the plating fluid(s) from the vessel, and removing the substrate from the vessel after the metal has been deposited on the substrate.

The method also preferably comprises introducing the fluids discreetly and sequentially, and removing the fluids discreetly and sequentially.

The method preferably comprises controlling an isostatic pressure within the vessel. The method may also comprise disposing a cathode in the vessel and sending an electrical current to the cathode.

The method preferably comprises controlling a temperature of fluid(s), preferably to within approximately +/- 1 ºC. The method also preferably comprises heating and cooling the plating fluid preferably at a rate faster than approximately 0.5 ºC per second, more preferably at a rate faster than approximately 1.0 ºC per second, and most preferably at a rate faster than approximately 2.5 ºC per second. The temperature of the fluid(s) is affected before introducing it into the vessel or while inside the vessel.

The method also preferably comprises providing a baffle system and affecting the flow of the fluid(s) within the vessel using the baffle system.

The method preferably comprises providing a holding apparatus and disposing the holding apparatus in the vessel, wherein the holding apparatus secures the substrate within the vessel. The holding apparatus preferably comprises a vacuum chuck comprising at least one vacuum cavity. The method preferably comprises disposing a deformable membrane on the cavity(ies) and disposing the substrate on the membrane. Vacuum is preferably applied to secure the substrate to the vacuum chuck.

Preferably, a boot comprising an edge skirt is provided and the boot is disposed on the vacuum chuck. An electrical bridge contact may be disposed in the boot and an electrical current is sent through the bridge contact.

A primary object of the present invention is to provide for the plating of a substrate while keeping the substrate in position throughout the entire plating process.

Another object of the invention is to provide for better control of autocatalytic plating processes, particularly with respect to small substrates.

A primary advantage of the present invention is the ability to finely control the plating processes with regard to, but not limited to, initiation rates, deposition rates, temperature control, and pressure control.

Another advantage of the present invention is the ability to reduce the volumes required for plating.

Another advantage of the present invention is the ability to minimize the risks of damage in plating small, expensive substrates and thus reduce the costs inherent in such damage.

Other objects, advantages and novel features, and further scope of applicability of the present invention are set forth in part in the detailed description to follow, taken in conjunction with the accompanying drawings, and in part will become apparent to those skilled in the art upon examination of the following, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The accompanying drawings, which are incorporated into, and form a part of, the specification, illustrate one or more embodiments of the present invention and, together with the description, serve to explain the principles of the invention. The drawings are only for the purpose of illustrating one or more preferred embodiments of the invention and are not to be construed as limiting the invention. In the drawings:

Fig. 1 is a perspective view of the preferred embodiment of the vessel of the present invention;

Fig. 2 is a cross-sectional view of the embodiment of Fig. 1.

Fig. 3 is a cross-sectional view of the preferred embodiment showing the application of vacuum into the vessel;

Fig. 4 is a cross-sectional view of the preferred embodiment showing the introduction of a plating solution;

Fig. 5 is a cross-sectional view of the preferred embodiment showing the circulation of a plating solution;

Fig. 6 is a cross-sectional view of the preferred embodiment showing the purging of a plating solution;

Fig. 7 is a cross-sectional view of the preferred embodiment showing a rinsing process;

Fig. 8 is a perspective view of the preferred embodiment showing multiple solution nozzles;

Fig. 9 is a cross-sectional view of the preferred embodiment of the vacuum chuck;

Fig. 10 is a perspective view of the preferred embodiment of the vacuum chuck;

Fig. 11 is a cross-sectional view of the preferred embodiment of the vacuum chuck showing the initial application of vacuum;

Fig. 12 is a cross-sectional view of the preferred embodiment of the vacuum chuck showing the subsequent application of vacuum;

Fig. 13 is a cross-sectional view of the preferred embodiment of the vacuum chuck showing the release of vacuum through the center shuttle;

Fig. 14 is a cross-sectional view of the preferred embodiment of the vacuum chuck showing the release of vacuum through the center shuttle;

Fig. 15 is cross-sectional view of the edge skirt of the preferred embodiment;

Fig. 16 is a cross-sectional view of the seal created by the edge skirt of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The preferred embodiment of the present invention comprises a metal plating (i.e., metal deposition) apparatus and method. The apparatus comprises a vessel or other enclosure to contain a substrate to be plated while the substrate is subjected to one or more plating processes and/or materials and fluids. Such processes include the electrolytic and electroless (i.e., autocatalytic) deposition of metal(s). As used herein, "substrate" is defined as any object comprising a surface onto which metal deposition is to occur, including, but

not limited to, a semiconductor wafer. The present invention provides for the plating of a substrate in a single vessel without the need to transfer the substrate to other vessels for exposure to other plating fluids or process steps. As used herein, a "plating fluid" is any fluid to which a substrate is exposed during a plating process including, but not limited to, chemical solutions, rinsing solutions, and metal solutions. In the preferred embodiment, the apparatus also comprises a controllable source of a plating fluid. Such a controllable source preferably comprises any source and delivery system known in the art including, but not limited to, containers such as tanks or other vessels linked to conduits for the transfer of fluids wherein the delivery may be controlled by any number of systems such as, for example, temperature control systems, pressure control systems, pumps, valves, etc., or manual control.

In the preferred embodiment, the apparatus further comprises a chuck, preferably a vacuum chuck, to hold the substrate in a desired position during the process(es). In the preferred embodiment, the apparatus and method are particularly suited for use in the semiconductor industry, but may be utilized wherever the indiscriminate deposition of metal onto surface areas must be avoided and/or where a greater level of control over the deposition of the metal is desired such as for the autocatalytic deposition of ceramic substrates or other types of electronic substrates. Although the apparatus and method of the present invention may be utilized for both electrolytic and autocatalytic plating, the remainder of this description focuses on autocatalytic plating.

As depicted in Fig. 1, the preferred embodiment of the present invention comprises sealed plating vessel **20** within which an item/substrate to be plated, such as substrate **100** (depicted in the figures as a wafer), remains during the entire plating process. Vessel **20** is preferably hydrostatically sealable. The plating fluids to which substrate **100** is exposed are preferably introduced discreetly (i.e., so that the unwanted contamination of one fluid with another does not occur) into the cell, thereby allowing for the sequential introduction of fluids at the appropriate process step. The present invention, therefore, preferably provides for a closed loop system between the source of the plating fluids and the vessel **20**.

Although the plating of one substrate **100** is described herein and is representative of the preferred embodiment, other embodiments of vessel **20** permit the plating of a plurality of substrates, preferably fixed in a tight arrangement to increase the total throughput.

Vessel **20** preferably comprises a cover such as dome **22** which is preferably disposed over a bottom portion such as base plate **24**. Any shape or configuration for vessel **20** may be utilized in accordance with the present invention, although a domed structure with a circular base is preferred. Laminar flow formation is preferably promoted by utilizing a non-rectangular shape of cell **30** adjacent to solution inlet **26**. Base plate **24** is preferably machined and preferably comprises stainless steel, plastic, or other rigid material. Dome **22** preferably comprises supply port **26**, which in the preferred embodiment is preferably annular, for the introduction of fluids into vessel **20**. Dome **22** also preferably comprises return port **28** for the return flow of fluids out of vessel **20**. Although a dome, base plate, and ports are described herein, any structure or means known in the art to provide for a sealable vessel and to provide access therein for the introduction and expelling of fluids may be utilized.

In the preferred embodiment, heating and cooling controls described below are provided. Such control of temperature is more effective if the mass of vessel **20** is reduced. Therefore, in the preferred embodiment, certain dimensions including, but not limited to, wall thickness are minimized in manners well-known in the art to provide for greater temperature control.

Fig. 2 shows a cross-section of the preferred embodiment of vessel **20**. As dome **22** is fitted over base plate **24**, enclosed cell **30** is formed within vessel **20**. Coupling nozzle **36** is preferably disposed on supply port **26** and return port **28** to connect fluid supply conduit **50** to supply port **26** and to connect fluid return conduit **52** to port **28**. Fluid supply conduit **50** transfers solution **200** (which may comprise any fluid to be introduced into vessel **20**, such as, but not limited to, chemical plating solutions) from solution tank **54** and into cell **30**, preferably through the use of pump **56**. Fluid return conduit **52** returns solution **200** to tank

54. Preferably, a flow and pressure control system, preferably comprising valve **60**, pressure regulator **62**, and filter **64**, is disposed along fluid return conduit **52**.

Baffle system **88**, as shown in Fig. 2a, is preferably disposed within cell **30** (securing means not shown) to improve the flow quality of fluids within cell **30**. As plating fluid **200** passes about and/or through baffle system **88**, a pressure of the fluid, within cell **30**, as described below, is distributed and improves laminar flow. Any design for baffle system **88** known in the art to control the flow of fluids may be utilized.

Seal **34** is preferably provided, although any means known in the art for ensuring the containment of fluids and gases within cell **30** may be utilized. Drain basin **38** is preferably disposed under base plate **24** to collect fluids when dome **22** is separated from base plate **24**. Released fluids are preferably collected through drain return cup **68** and sent via drain conduit **70** to storage (not shown) or to tank **72**. Filter **74** may be disposed on drain conduit **70**.

Vessel **20** preferably comprises an apparatus for holding the object to be plated (e.g., substrate **100**) in a fixed or other desired position during the plating process. The apparatus preferably comprises chuck **40**, and in the preferred embodiment, comprises a vacuum chuck. The overall design of chuck **40** is preferably circular, but any geometric shape may be utilized. In the preferred embodiment, chuck **40** comprises a base that in the preferred embodiment comprises base plate **24** (although chuck **40** can comprise a separate, dedicated base) which in turn preferably comprises vacuum chamber **44** and vacuum cavities **46, 46'**. Vacuum cavities **46, 46'** may number one or more, although two are depicted in the figures.

Chuck **40** also preferably comprises diaphragm **42** which is disposed over, and completely seals, vacuum cavities **46, 46'**. Notwithstanding the number of vacuum cavities depicted throughout the figures, one or more such cavities may be utilized. Membrane **42** preferably comprises a deformable sealing material, such as a flexible or elastomeric membrane that can deform in response to vacuum and that preferably comprises a material

that is chemically non-reactive and temperature resistant, such as, but not limited to, thin rubber silicone. In a method of the present invention, substrate **100** is disposed on diaphragm **42**.

Vacuum port **48** is connected to a vacuum source system (not shown). Fig. 3 shows how in the preferred embodiment, as vacuum is applied into vacuum chamber **44** through vacuum port **48**, vacuum chamber **44**, and vacuum cavities **46, 46'**, diaphragm **42** is distorted so that vacuum void **47** forms between diaphragm **42** and substrate **100**. The vacuum within vacuum void **47** holds substrate **100** against base plate **24** and seals the contact surfaces between substrate **100** and diaphragm **42**. Vacuum cavities **46, 46'** preferably comprise a series of concentric rings or grooves that are sized to create a footprint pattern smaller than the main diameter of substrate **100**. Thus, the back side of substrate **100** is protected from exposure to catalysts or other chemicals.

Fig. 4 shows the introduction of electroless chemical solution **200** which preferably flows through port **26** into cell **30** preferably until cell **30** is filled to the desired level. Return port **28** is preferably provided to permit the return or cycling of solution **200** back to its source, such as tank **54**. Fig. 5 schematically shows an embodiment of the present invention which provides for a continuous circulation of solution **200** through cell **30**. The duration of the flow of solution **200** through cell **30** and the residence time for a given portion of solution **200** within cell **30** is determined by the process flow and the desired amount of exposure to each solution.

In the preferred embodiment of the present invention, return conduit **52**, through which solution **200** is returned to its source, is linked to a pressure system preferably comprising elements such as valve **60** and pressure regulator **62**. By regulating the back pressure with valve **60**, isostatic pressure may be introduced and/or maintained within cell **30** and can act upon the surface of substrate **100** at the reaction interface. During plating, the pressure within cell **30** is preferably maintained above atmospheric pressure.

As noted, typical electroless plating processes suffer from the spurious deposition of

metal in areas where deposition is not desired and must be inhibited to maintain an acceptable level of process control. Modulating the hydrostatic pressure of the plating solution surrounding the substrate being plated can control the electroless plating deposition rate. Specifically, increasing the hydrostatic pressure in a closed space that holds both the plating fluids and the substrate to be plated will reduce the plating rate and increase the threshold for plating initiation in direct proportion to the overpressure. This approach, in part, involves the suppression of hydrogen gas generation at the boundary layer between the metal surface and the plating fluid. The plating rate can be retarded by increasing the direct application of hydrostatic pressure to the system at up to several bars of overpressure. At pressures greater than one atmosphere, the plating reaction can be suspended so that there is no net metal deposition onto the substrate.

Therefore, this preferred application of isostatic back pressure in the present invention provides an additional kinetic property or additional kinetic control that provides for better process control without the need to add organic inhibiters. The kinetic control provided by the present invention permits the use of autocatalytic gold and other autocatalytic pressure chemical formulations which have previously proven too reactive and too difficult to control, as they require a high level of organic inhibiters that typically result in an undesirable metallurgical structure/material.

Through the application of hydrostatic pressure, the present invention comprises the precise control of both the initiation and rate of plating by directly controlling the physical environment of the item to be plated. Other examples of the better control offered by the present invention, discussed more fully below, are the control over temperature and the electrical activation of various surfaces to provide a more refined control over the deposition process. Such control is particularly valuable within the semiconductor industry because the line feature associated with semiconductor patterns is too small to permit a high incidence of organic material co-deposits. Such co-deposits reduce the metallurgical density of the resulting metal pattern. By controlling the environment as with the present invention, the requirement to incorporate complexing agents, stabilizers, inhibitors, etc. is largely, if not completely, obviated. The present invention, therefore, provides for a metal

deposit that is free of the co-deposited and incorporated organic species commonly found in the metal deposits resulting from conventional electroless plating.

The pressure of the solution in cell **30** is regulated by pressure valve **38** or other type of pressure regulator, which preferably pressurizes the cell to one or two atmospheres above open cell, or ambient, pressure. However, any pressure may be utilized. For example, valve **38** introduces back pressure into cell **30**, which optionally is monitored and controlled by pressure gauge **62** or other controller. The ability to pressurize cell **30** provides control over pressure dependent characteristics of the plating process, for example deposit kinetics, which results in improved performance and an improved deposit.

Controlling the pressure in cell **30** also improves solution exchange and ion supply on all surfaces of substrate **100**, including deep filled vias and planer surface areas. Thus, submicron structures can be successfully plated and nanoscale vias can be filled uniformly.

With regard to electrolytic plating, pressurizing cell **30** also suppresses the formation of gases such as hydrogen at the deposition interface, (i.e. the cathode, or substrate, surface). These gases cause undesirable porosity or voids resulting in micropittings that typically occur in a deposit on the surface of the cathode. Gases such as hydrogen also may reduce the mechanical strength of the deposit; if hydrogen is left in the boundary area, brittle deposits or highly stressed deposits may be formed, resulting in tensile failure and possibly resulting in the deposit peeling back from substrate **100**. The integrity of the bond of the deposit, such as a metallic interconnect, to substrate **100** is critical to assure the high reliability necessary for electronic components.

For applications in the submicron range, particulates, pores, and micropittings that would normally be acceptable in traditional plating applications are not tolerable because of the small size of the features to be plated as well as the required thinness of the deposit. Thus, the overall control of micropittings is of paramount importance if semiconductor wafers are to be electroplated. By using pressurization to minimize gas formation, the integrity of the initial deposit on the surface of substrate **100** (when the voltage or the

potential is at its highest), which creates the first boundary layer between substrate **100** and the metal being deposited, will be greatly improved. This results in a surface morphology of sufficient quality to successfully plate submicron structures.

Also, the ability to raise the pressure in cell **30** allows for the use of temperatures higher than used conventionally such as, for example, temperatures higher than the typical 85 ºC.

As shown in Fig. 6, after the desired processing is complete, dome **22** can be lifted to create evacuation port **80**. Evacuation port **80** preferably comprises the open area encircling base plate **24** and dome **22** as they are separated, thereby providing for the a complete purging of solution **200**. All purged fluids, including solution **200**, are preferably collected in basin **38**. Fig. 6 shows catch basin **38** which is disposed over one or more of return cup **68** (such as return cups **68, 68', 68", 68"', 68"", 68""'** as shown in Fig. 8).

As shown in Fig. 7, after the purging of solution **200**, another coupling nozzle **36'**, which is connected via conduit **156** to rinsing source **154** (containing rinsing fluid **158** such as, but not limited to, deionized water), and is preferably connected to port **26** and/or port **28** to inject rinsing fluid **158** into cell **30** to completely rinse out solution **200** and to purge rinse water **158**. Vessel **20** can be in an open or a closed position during this step.

The injection and purging of water can be repeated a number of times as described. Subsequent solutions are preferably applied sequentially by attaching several coupling nozzles such as coupling nozzles **36, 36', 36", 36'"** shown in Fig. 8. All of the steps can be repeated for any of each subsequent exposure to a solution. Thus, solutions may be applied without contaminating one with another, and they may be applied in a controlled time fashion to provide for accuracy in the process and to build the desired metal deposit film onto substrates.

To apply fluids sequentially, nozzle turret system **136** or other similar (to accomplish the same task) system is preferably utilized in one embodiment, as shown in Fig. 8, which

can, for example, rotate to sequentially dispose distinct nozzles on vessel **20**. By multiplying the number of tanks, the number of nozzles and the number of return cups, an unlimited number of process steps can be applied to the vessel to provide a sophisticated process control capability without transferring substrate **100** or other substrates from vessel to vessel. The present invention also allows for the pressurization of the work zone with an inert gas, such as nitrogen, to control or eliminate oxidation on the metals between process steps (i.e., elimination of exposure to oxygen).

An example of the method of the present invention applied to an ENIG plating deposition comparable to the conventional electroless plating process sequence described in the background section above is as follows:

1. filling the cell with an aluminum cleaner;
2. rinsing the cell with deionized water;
3. filling the cell with a zincate solution;
4. rinsing the cell with deionized water;
5. introducing a nickel electroless plating bath solution to the cell and heating the cell to operating temperature;
6. rinsing the cell with deionized water;
7. introducing an immersion gold bath solution to the cell and heating the cell to operating temperature; and
8. rinsing the cell with deionized water.

In the present invention, plating solution **200** can be held outside vessel **20** at a temperature just below the minimum plating temperature and quickly raised to the optimum operating temperature just as plating solution **200** is introduced into cell **30**. Plating solution **200** can be heated either by heating tank **54**, by passing it through thermostatically controlled heating coil **58** (shown in Fig. 2) or by embedding a heating system directly within the walls of vessel **20**, such as, for example, incorporating a heating/cooling jacket **59** adjacent walls **32** of dome **22** as shown in Fig. 2a. The heating system can comprise a heating/cooling jacket through which a thermal control fluid such as, but not limited to, water

and/or glycol can be circulated. Other thermally conductive materials that may be utilized in such a heating system include gases. Also, a combination of electrically resistive heating and gaseous cooling, thermoelectric heating and cooling, and combinations thereof may be utilized. In effect, any heating/cooling system known in the art may be used to regulate temperature. Also, a temperature control system may be combined with such a heating system, thermocouples or other systems may be included to provide feedback to the temperature control system to keep plating solution **200** within a desired temperature within approximately +/- 1 ºC.

In addition to maintaining a constant temperature, the present invention provides for the ability to quickly heat and/or cool a plating fluid. Such cooling and heating rates are preferably at rates of greater than approximately 2 ºC per second, more preferably at rates of greater than approximately 1 ºC per second, and most preferably at rates of greater than approximately 0.5 ºC per second.

The temperature regulating feature of the present invention is particularly helpful given that electroless plating processes are highly dependent upon solution temperatures. Most autocatalytic plating chemical solutions are designed to operate within a very narrow range of temperature to achieve their catalytic effect and can heat in situ.

The present invention provides for better and more efficient process management in part because the volume of the cell can be much smaller such as approximately 1-5 liters (but can be much smaller such as 0.5 liters or smaller) in comparison to the tank facilities utilized in conventional plating processes. The relatively smaller volume of plating solution **200** in use at any one time facilitates a higher degree of thermal management and plating rate control than can be afforded by the open tank electroless plating methodology. The smaller size is especially suited when using a "static" plating embodiment described below wherein fluid is not circulated within vessel **20** while deposition is taking place.

Another benefit of the reduced volume is that, because the amount of the organic chemicals in the solution is reduced, the resulting metallurgical quality of the deposited film

is higher. For example, the use of autocatalytic gold allows thicker deposit features that exceed 7 micrometers, thereby allowing an electroless, post forming tool to form columns in precious metals such as gold and platinum.

Although the figures and the preferred embodiment describe herein describe an apparatus and method wherein plating fluids are moved into, within, and out of vessel **20**, another embodiment provides that plating fluids may be introduced into vessel **20** and held statically (i.e., not circulated within vessel **20**). In this "static fluid", non-flow embodiment, plating reactions occur between the static chemical solutions and the surface of substrate **100**. The initiation and rate of plating is controlled by temperature control and/or hydrostatic overpressure control. Operating the plating process in this static fluid mode provides for rigorous control of the volume of plating fluid **200**. In other words, the amount of chemical used per substrate **100** can be titered to the point of use, and it is not necessary to hold the entire the source of plating solution **200** at operating temperatures. The volume of plating fluid **200** can be heated at either the point of use (i.e., within vessel **20**) or immediately preceding the introduction of plating fluid **200** in to vessel **20**. Therefore, the activity and performance of plating chemicals is preserved even as the amount of chemicals expended per substrate during the plating process is conserved. This embodiment is particularly suitable when the dimensions of vessel **20** are greatly reduced in volume and/or in terms of such dimensions as wall thickness, etc.

In the preferred embodiment, vessel **20** comprises electrode **76**, which preferably comprises a ring-shaped cathode. Electrode **76** is disposed within vessel **20** (connection not shown) and can be electrically biased to walls **32** or substrate **100**. Electrode **76** can be employed to electrically activate the substrate to be plated to initiate the plating process. Electrode **76** can also be used to prevent plating deposition from going out of solution and onto vessel **20**.

Electrode **76** is connected to direct current voltage power supply **78**. Base plate **24** and dome **22**, which are preferably manufactured of a metal that can be utilized as an electrode, such as, but not limited to, stainless steel or titanium, comprise the counter-

electrode (i.e., anode). This provides a voltage potential on the surface of base plate **24** and dome **22**, protecting them from metal deposition. The use of base plate **24** and dome **22** as an anode can also provide a control scheme to accelerate the initiation of the electroless process, which is typically controlled by bath loading. The control scheme "fine tunes" the control over the plating process. Initiation can be controlled by increasing or decreasing the voltage into cell **30**.

In accordance with the present invention, the polarity and amplitude of bias voltage of ring electrodes can be varied to facilitate anodic protection of the cell elements exposed to the plating solution during the process (conventional electroless plating processes can control plating initiation only by adjusting levels of plating bath additives and bath temperature). The cell design has a resident cathode electrode which can be used to compensate dynamically for variations in the exposed wafer surface area to be plated (conventional electroless plating processes have a fundamental limitation as to the plating surface load which can be plated at any given time which places limits on the flexibility of the conventional electroless plating line hardware).

As detailed, the preferred embodiment of the vacuum chuck is shown in Figs. 9-16. Vacuum chuck **140** preferably comprises center articulating shuttle **180** for interfacing substrate **100** with automated end effectors (e.g., Y-shaped effector **220**) and robotics for wafer handling and wafer automation. Vacuum chuck **140** is preferably rotatable, which provides advantages in uniformity of deposit. Center articulating shuttle **180** is preferably disposed within base plate **124**. As shown in Fig. 11, when substrate **100** is positioned on chuck **140**, center articulating shuttle **180** holds substrate **100** above base plate **124** to expose an outer perimeter of the back side of substrate **100**. Substrate **100** can then be carried from the back side such as, for example, by effector **220** as shown in Fig. 10. Fastener **118** holds diaphragm **142** to base plate **124** so that only that portion of diaphragm **142** disposed on center articulating shuttle **180** rises above base plate **124**. Thus, handling can be interfaced with conventional robotics.

Fig. 11 show substrate **100** held to center articulating shuttle **180** as vacuum is applied through port **186** into vacuum chamber **182** and vacuum cavities **184, 184'** (any

number of cavities may be provided). The vacuum causes diaphragm **142** to deform, thereby creating corresponding voids **188, 188'**. Fig. 12 shows center articulating shuttle **180** lowered into position so that substrate **100** is set onto backing plate **124**. Fig. 12 shows the application of vacuum through port **148** into vacuum chamber **144** and cavities **146, 146', 146"** (any number of cavities may be provided). This causes diaphragm **142** to deform and create corresponding voids **147, 147', 147"** so that substrate **100** is held onto, and sealed against, backing plate **124**. Fig. 14 shows shuttle **180** retracted further upon release of vacuum in chamber **182** so that it does not interfere with the rotation, if such is desired, of substrate **100**.

In the preferred embodiment, edge seal boot **190** is disposed at the periphery of diaphragm **142**. Edge seal boot **190** comprises any flexible material that may provide a seal. Edge seal boot **190** may be utilized in conjunction with any type vacuum chuck such as, but not limited to, vacuum chuck **40** described in Figs. 1-7, although it is depicted herein in relation to chuck **140**. As detailed in Fig. 15, edge seal boot **190** is constructed so that it provides for vacuum chamber **144** to extend above and around the periphery of substrate **100**, preferably when center shuttle **180** is in a position prior to bringing substrate **100** into full contact with base plate **124**. Edge seal boot **190** preferably comprises edge skirt **192** which collapses upon the application of vacuum within vacuum chamber **144**. As shown in Fig. 16, upon the application of vacuum through port **148**, edge seal boot **190** preferably collapses. The design of the wall thickness of edge bladder **190** is preferably in a staged fashion so that a controlled collapse of edge seal boot **190** pulls edge skirt **192** into contact with the surface of substrate **100**, creating an effective air and gas seal on the surface of substrate **100**. Because a hydrostatic seal is created which protects the edges and backside of substrate **100** from contact with plating chemicals, there is no need for masking or coating the backside of the wafer.

With respect to electrolytic plating, an electrolytic contact with substrate **100** is not required but is preferably incorporated by providing electrical bridge contact **196** and electrical buss ring **194** as shown in Fig. 15. In practice, substrate **100** is placed concentrically within electrical buss ring **194** which has a diameter greater than the main

diameter of substrate **100** so that substrate **100** can nest within electrical buss ring **194**. The surface of ring **194** is exposed to the top side and is approximately flush with the surface of substrate **100**.

Electrical bridge contact **196** is preferably embedded in edge seal boot **190**, and preferably comprises an evenly distributed array of contacts, preferably so that electrical bridge contact **196** is isolated when edge seal boot **190** is not under vacuum. When vacuum is applied and edge skirt **192** is pulled into contact with substrate **100**, electrical bridge contact **196** contacts ring **194** to cause an electrical contact to the surface of substrate **100**. This results in a continuity from a, preferably direct current, power supply, thereby bussing current in a 360 degree multi-point contact along the periphery of substrate **100**.

Edge skirt **192** also provides a seal to prevent contamination of the back side and the periphery are of substrate **100** from the copper electrolyte solution and also to isolate electrical contacts **196** from exposure to the electrolyte thereby preventing deposits from forming on electrical bridge contact **196**. This provides for an easier and less damaging removal of substrate **100** upon completion of electrolytic plating. This also reduces the maintenance required for electrical bridge contact **196** which would typically suffer from a build-up of deposits.

The bussing circuitry described above can be used in a notic and ketotic fashion and with pulse and periodic reverse regimes. Electrolytic plating processes benefit from the use of the described array of electrical bridge contact **196**. The result is a lower resistance bussing of the current from buss ring **194** to the surface of substrate **100** thereby requiring a lower voltage and providing preferential conditions for the electro deposition process.

Chuck **140** can be utilized in open and closed electroplating cells, in a vertical or horizontal position, and can be affixed to a bearing device (not shown) and rotationally actuated so that the leading edge effects due to electrodeposition from a flowing electrolyte are mitigated by rotating substrate **100** continuously through the electrodeposition process

to facilitate a homogeneous deposit thickness on the wafer.

Because plating processes typically occur at the final stage of wafer processing, a considerable investment in materials and work has already been made to a wafer before plating, and any damage to a wafer during plating results in a substantial loss of the investment. The method of the present invention provides a more reliable processing strategy with less risk than can be accomplished with conventional plating. Also, because the present invention allows for the plating of one wafer at a time, mistakes are less costly (e.g., conventional electroless plating processes operate on multiple wafers in parallel per plating tank step, so a deviation or defect in the process parameters in any given step/tank carries with it the attendant risk of damage to multiple wafers). However, multiple substrates may be plated in parallel according to the present invention. Thus, the present invention results in improved film quality, improved feature size capability, and a great reduction of risk to finished substrates.

The preceding examples can be repeated with similar success by substituting the generically or specifically described reactants and/or operating conditions of this invention for those used in the preceding examples.

Although the invention has been described in detail with particular reference to the preferred embodiments in the attachment, other embodiments can achieve the same results. Variations and modifications of the present invention will be obvious to those skilled in the art and it is intended to cover all such modifications and equivalents. The entire disclosures of all references, applications, patents, and publications cited above, and of the corresponding application(s), are hereby incorporated by reference.

CLAIMS

What is claimed is:

1. A plating apparatus comprising:

a pressurized, sealable vessel;

a controllable plating fluid source linked to said vessel;

a holding apparatus to secure a substrate within said vessel during plating of the substrate and until the plating of the substrate is complete; and

at least one opening through which one or more plating fluids pass in and out of said vessel.

2. The apparatus of claim 1 wherein the plating of the substrate comprises autocatalytic plating.

3. The apparatus of claim 1 wherein the substrate comprises a semiconductor wafer.

4. The apparatus of claim 1 wherein said linked controllable source and vessel comprise a closed system.

5. The apparatus of claim 1 further comprising a pressure control system to control a pressure of said plating fluid within said vessel to control isostatic pressure.

6. The apparatus of claim 1 wherein said controllable source comprises a system for the discreet, sequential introduction and removal of said plating fluids into and from said vessel.

7. The apparatus of claim 6 wherein said system comprises a plurality of nozzles and conduits.

8. The apparatus of claim 7 wherein said system comprises a sequentially rotating nozzle system.

9. The apparatus of claim 1 further comprising a temperature control system.

10. The apparatus of claim 9 wherein said temperature control system controls a temperature to within approximately +/- 1 ºC.

11. The apparatus of claim 9 wherein said temperature control system heats or cools said plating fluid at a rate faster than approximately 0.5 ºC per second.

12. The apparatus of claim 11 wherein said temperature control system heats or cools said plating fluid at a rate faster than approximately 1.0 ºC per second.

13. The apparatus of claim 12 wherein said temperature control system heats or cools said plating fluid at a rate faster than approximately 2.5 ºC per second.

14. The apparatus of claim 9 wherein said temperature control system is disposed outside of said vessel to affect a temperature of said plating fluid prior to said plating fluid entering said vessel.

15. The apparatus of claim 9 wherein said temperature control system is disposed over said vessel.

16. The apparatus of claim 9 wherein said temperature control system is disposed in said vessel.

17. The apparatus of claim 16 wherein said temperature control system is disposed in at least one wall of said vessel.

18. The apparatus of claim 1 wherein said vessel comprises a volume of less than less than approximately 5 liters.

19. The apparatus of claim 18 wherein said vessel comprises a volume of less than less than approximately 3 liters.

20. The apparatus of claim 19 wherein said vessel comprises a volume of less than less than approximately 2 liters.

21. The apparatus of claim 20 wherein a cell of said vessel comprises a volume of less than less than approximately 1 liter.

22. The apparatus of claim 21 wherein said vessel comprises a volume of less than less than approximately 0.5 liter.

23. The apparatus of claim 1 further comprising a baffle system disposed within said vessel.

24. The apparatus of claim 1 further comprising a cathode disposed in said vessel.

25. The apparatus of claim 1 wherein said vessel comprises:

a base plate; and

a cover removably disposed on said base plate.

26. The apparatus of claim 1 wherein said holding apparatus comprises a vacuum chuck.

27. The apparatus of claim 26 wherein said vacuum chuck comprises:

a base; and

at least one vacuum cavity in said base.

28. The apparatus of claim 27 further comprising at least one membrane disposed over said at least one cavity.

29. The apparatus of claim 28 wherein said membrane comprises a membrane that is deformable in response to a vacuum.

30. The apparatus of claim 29 wherein said membrane comprises an elastomeric material.

31. The apparatus of claim 27, said vacuum chuck further comprising a center shuttle disposed in said base.

32. The apparatus of claim 27 further comprising an edge seal boot disposed on said base.

33. The apparatus of claim 32 wherein said edge seal boot comprises an edge skirt to contact the substrate and seal a portion of the substrate.

34. The apparatus of claim 33 further comprising an electric bridge contact disposed in said edge skirt.

35. The apparatus of claim 34 wherein said electric bridge contact comprises an array of contacts.

36. A method for depositing metal on a substrate comprising the steps of:

providing a pressurized, sealable vessel;

securing the substrate within the vessel;

introducing one or more plating fluids into the vessel;

removing the one or more plating fluids from the vessel; and

removing the substrate from the vessel after the metal has been deposited on the substrate.

37. The method of claim 36 further comprising;

introducing the plating fluids discreetly and sequentially; and

removing the plating fluids discreetly and sequentially.

38. The method of claim 36 further comprising controlling an isostatic pressure within the vessel.

39. The method of claim 36 further comprising the steps of:

disposing a cathode in the vessel; and

sending an electrical current to the cathode.

40. The method of claim 36 further comprising controlling a temperature of at least one of the plating fluids.

41. The method of claim 40 comprising controlling the temperature to within approximately +/- 1 ºC.

42. The method of claim 40 comprising heating or cooling at least one of the plating fluids at a rate faster than approximately 0.5 ºC per second.

43. The method of claim 42 comprising heating or cooling at least one of the plating fluids at a rate faster than approximately 1.0 ºC per second.

44. The method of claim 43 comprising heating or cooling at least one of the plating fluids at a rate faster than approximately 2.5 ºC per second.

45. The method of claim 40 further comprising affecting the temperature of the at least one fluid before introducing it into the vessel.

46. The method of claim 40 further comprising affecting the temperature of the at least one fluid inside the vessel.

47. The method of claim 36 further comprising the steps of:

providing a baffle system; and

affecting the flow of the at least one fluid within the vessel using the baffle system.

48. The method of claim 36 further comprising the steps of:

providing a holding apparatus; and

disposing the holding apparatus in the vessel; and

wherein the holding apparatus secures the substrate within the vessel.

49. The method of claim 48 wherein the holding system comprises a vacuum chuck comprising at least one vacuum cavity.

50. The method of claim 49 further comprising the steps of:

disposing a deformable membrane on the at least one cavity; and

disposing the substrate on the membrane.

51. The method of claim 50 further comprising applying a vacuum to secure the substrate to the vacuum chuck.

52. The method of claim 49 further comprising the steps of:

providing a boot comprising an edge skirt; and

disposing the boot on the vacuum chuck.

53. The method of claim 52 further comprising the steps of:
disposing an electrical bridge contact in the boot; and
sending an electrical current through the bridge contact.

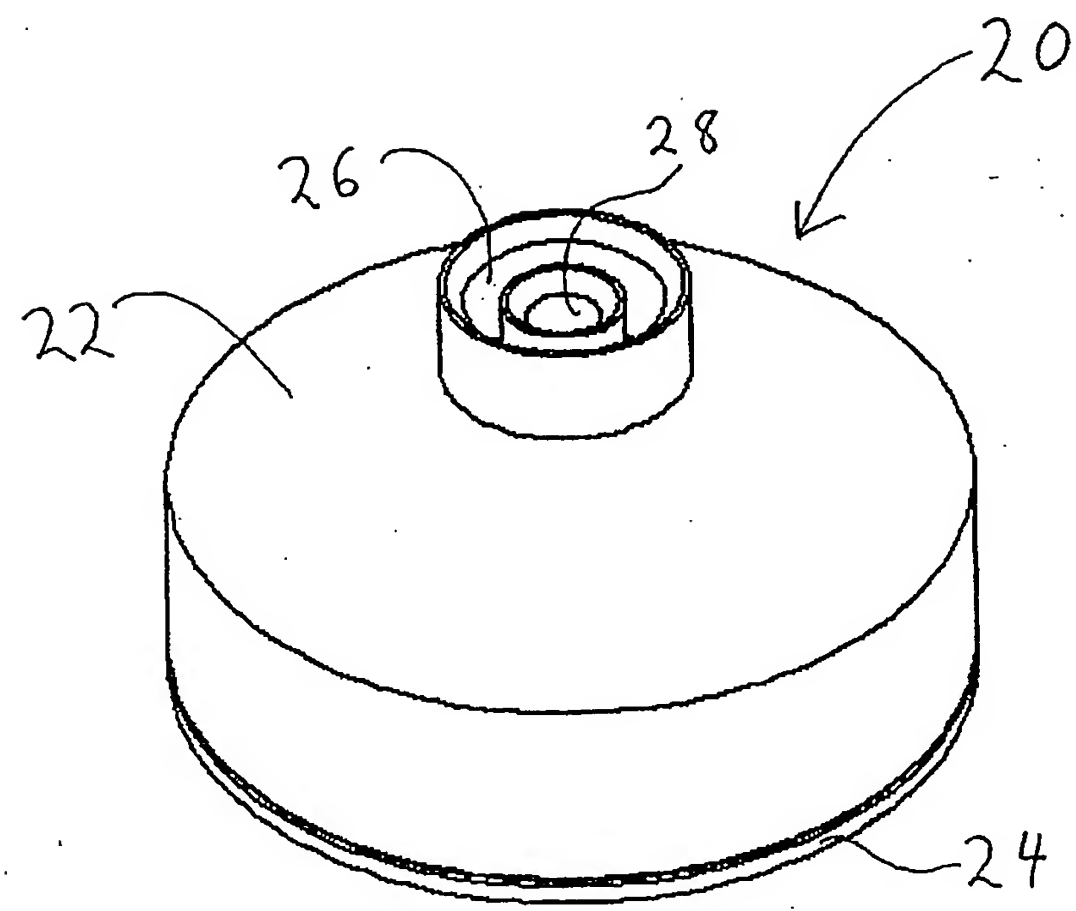

Fig. 1

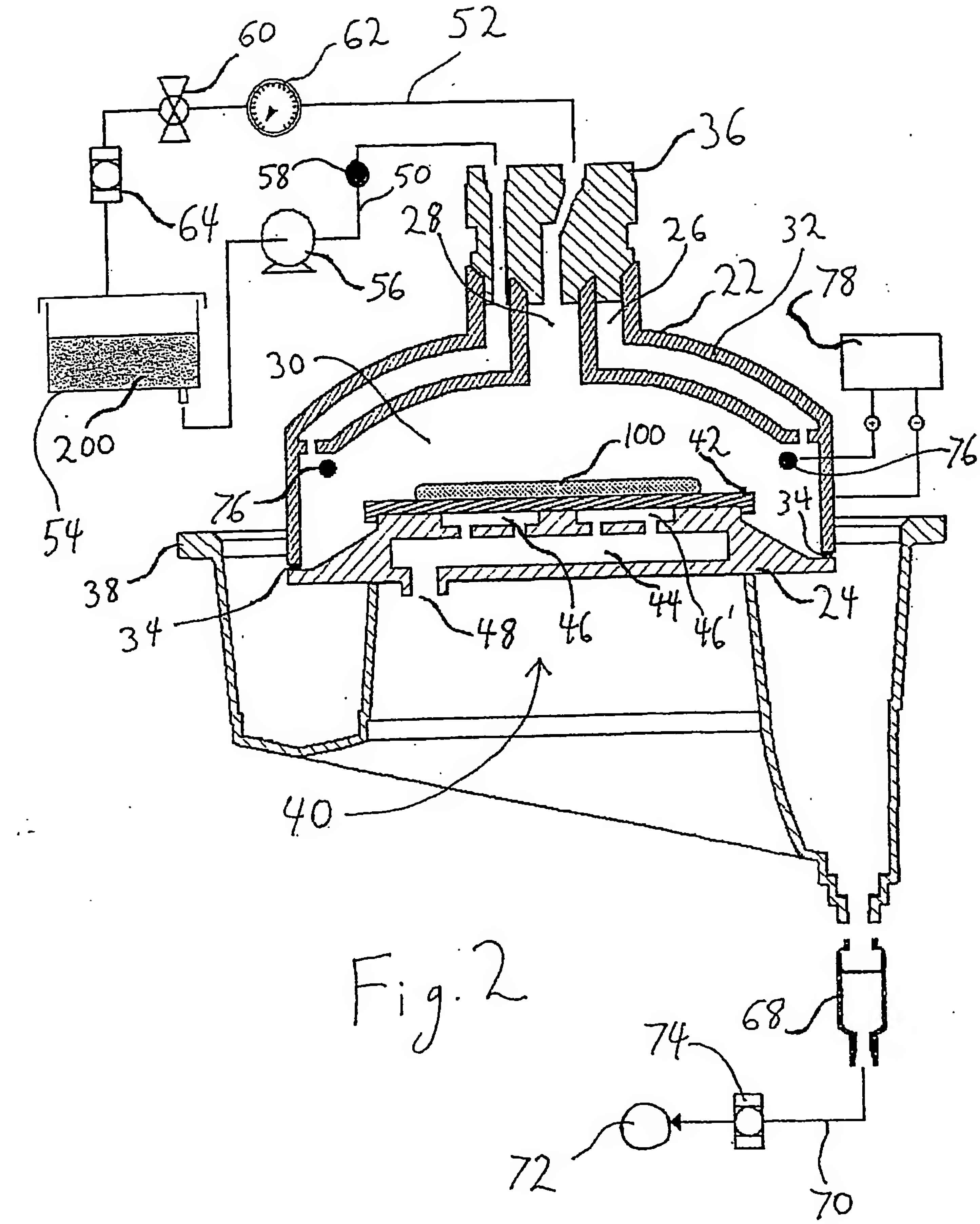
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Fig. 2

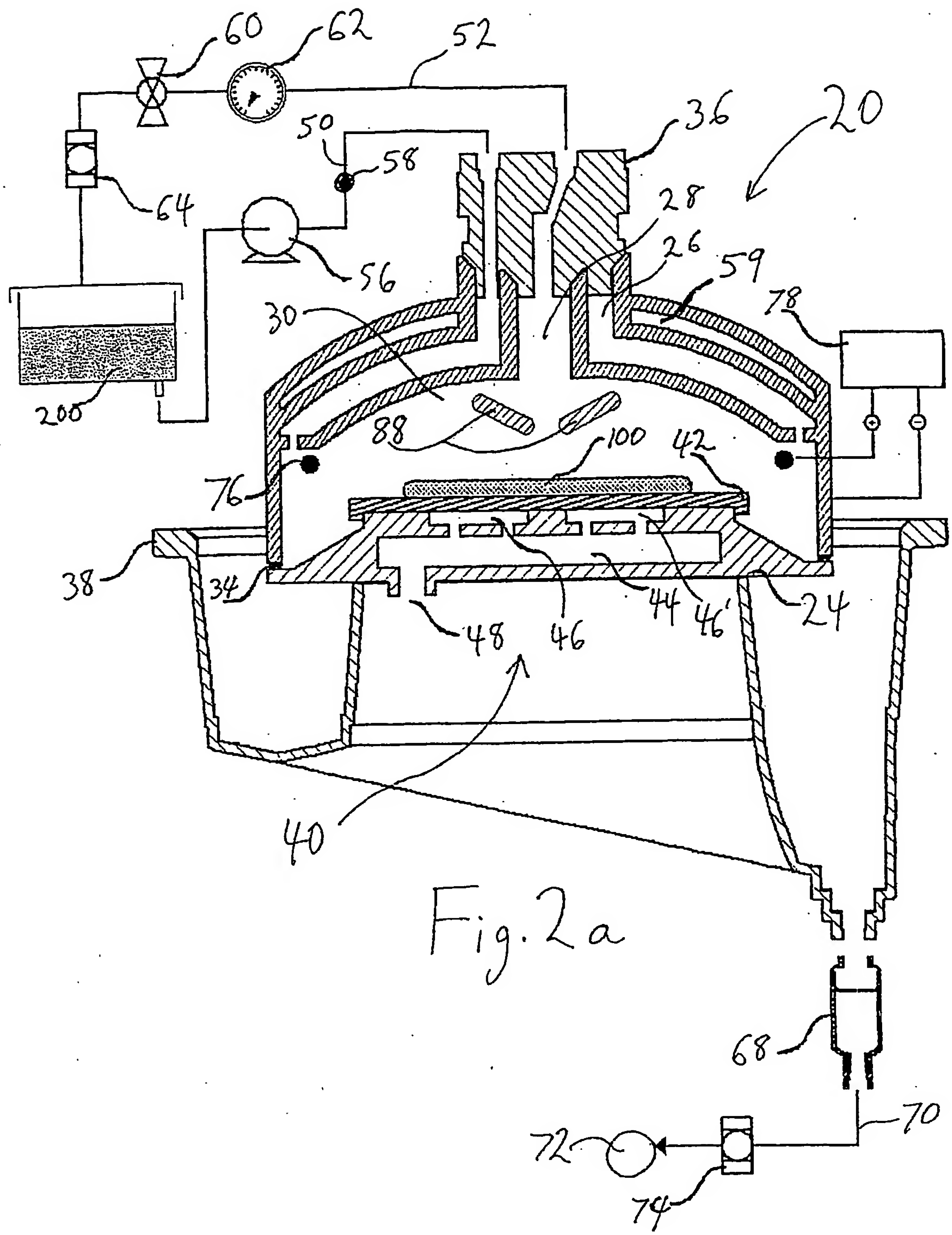
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Fig. 2a

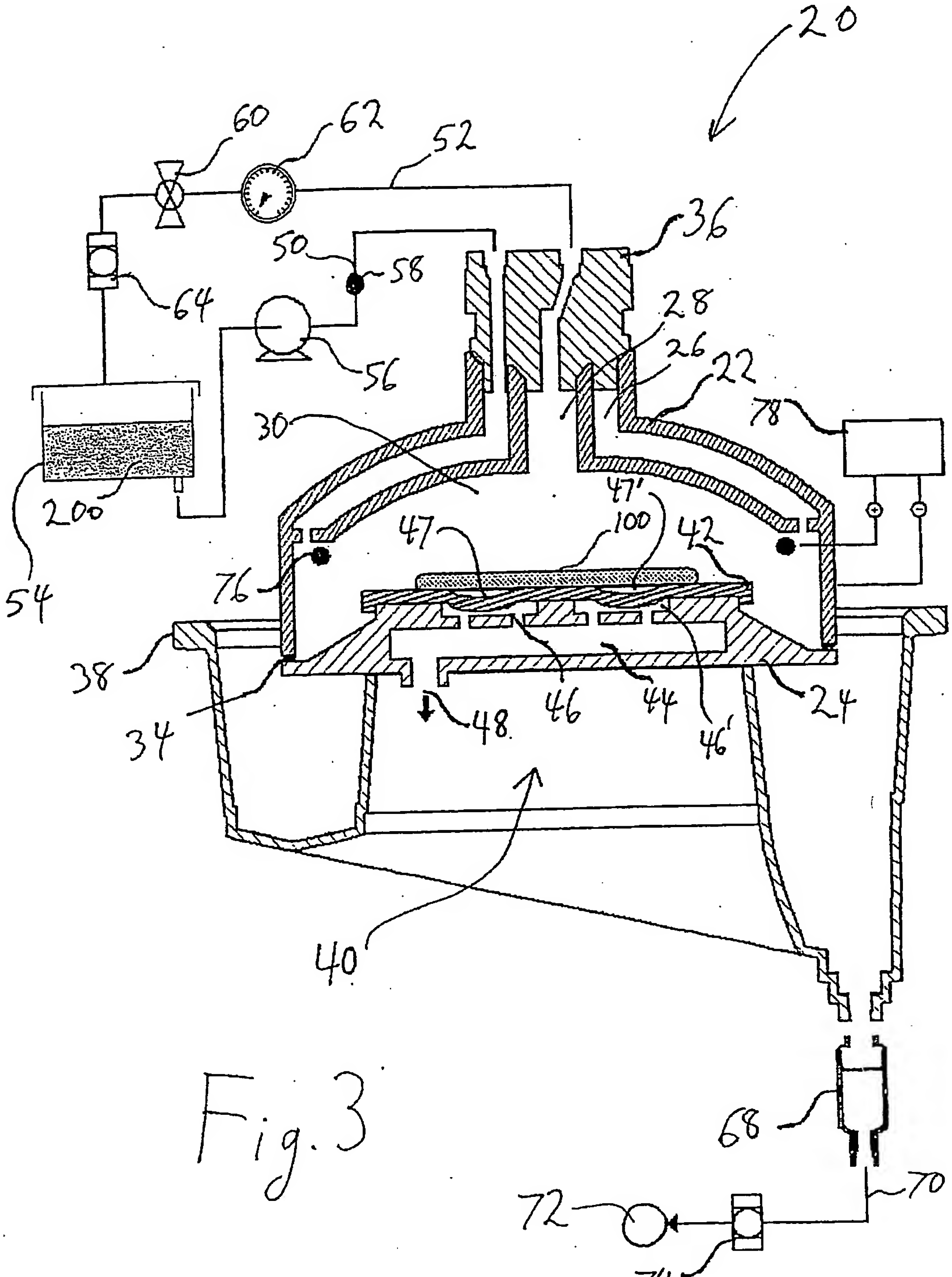
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Fig. 3

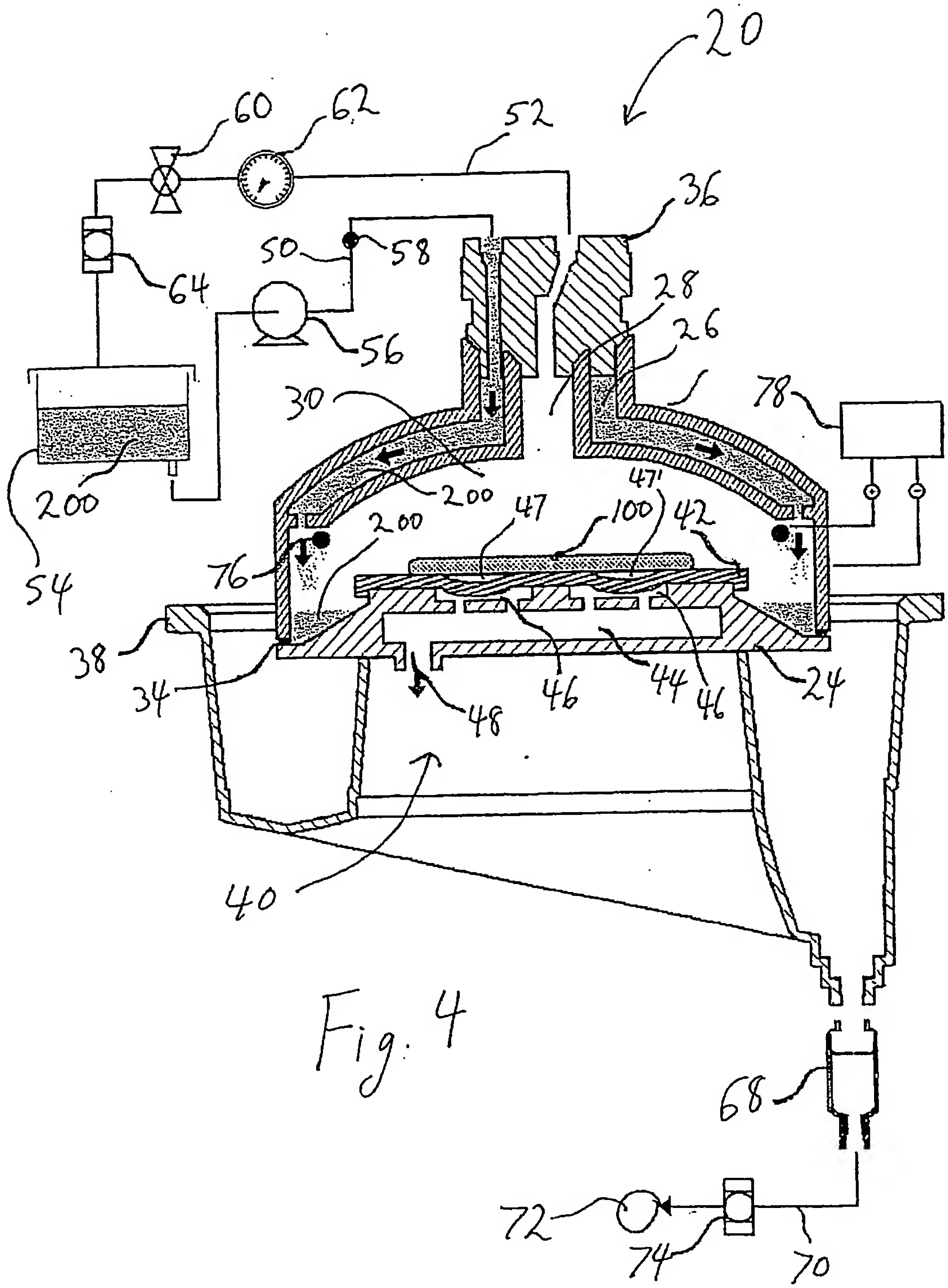
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Fig. 4

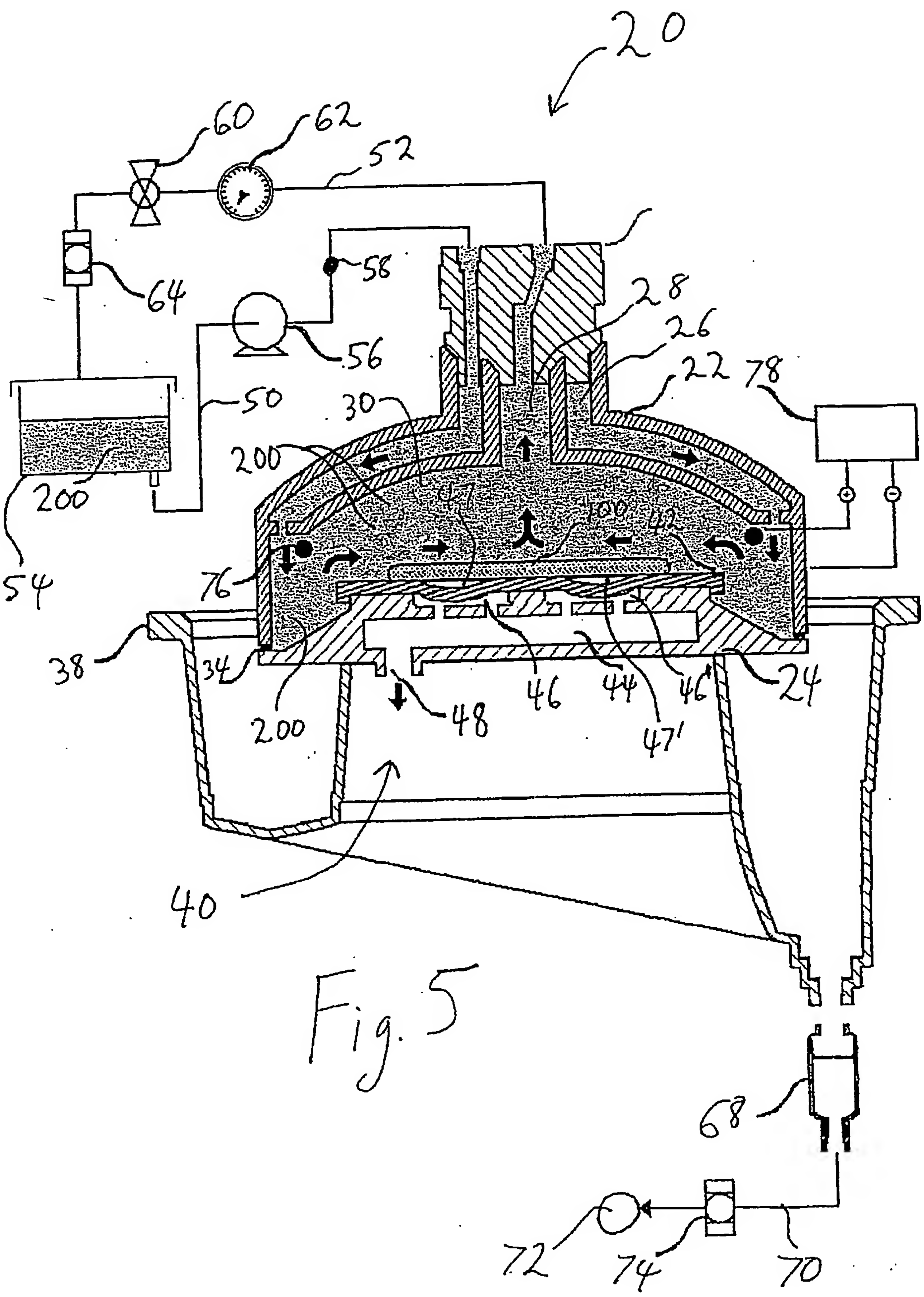
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Fig. 5

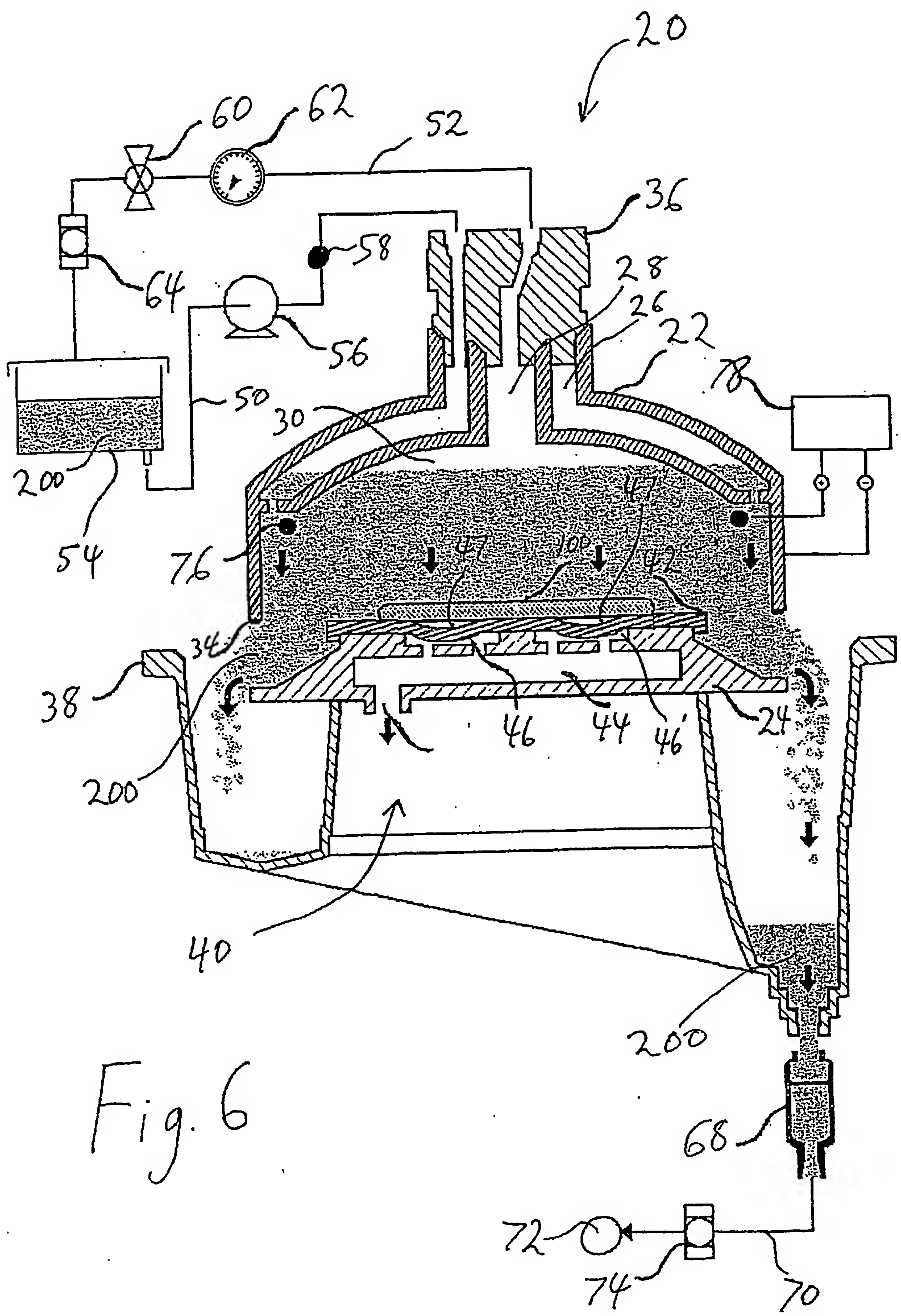
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Fig. 6

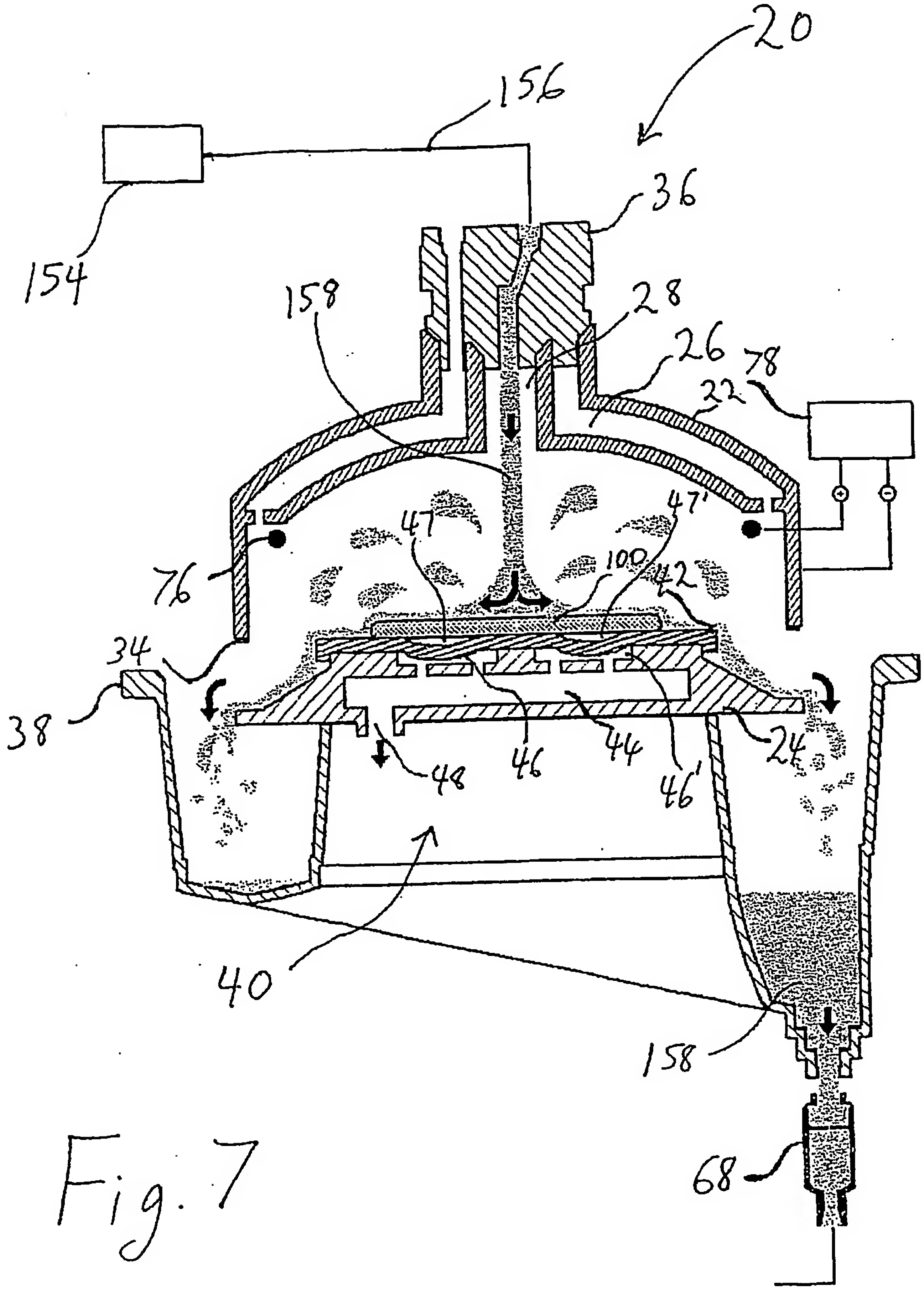
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Fig. 7

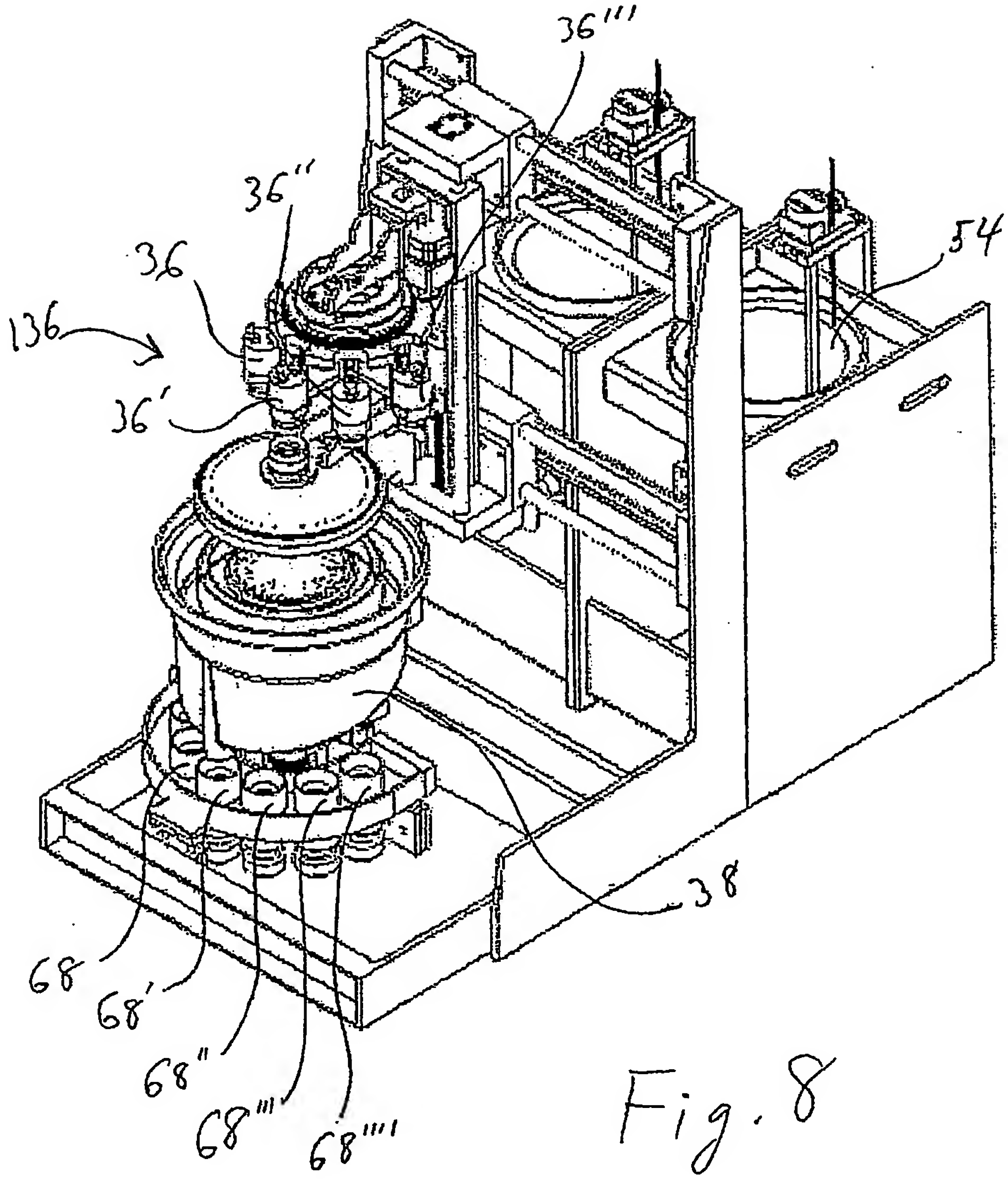

Fig. 8

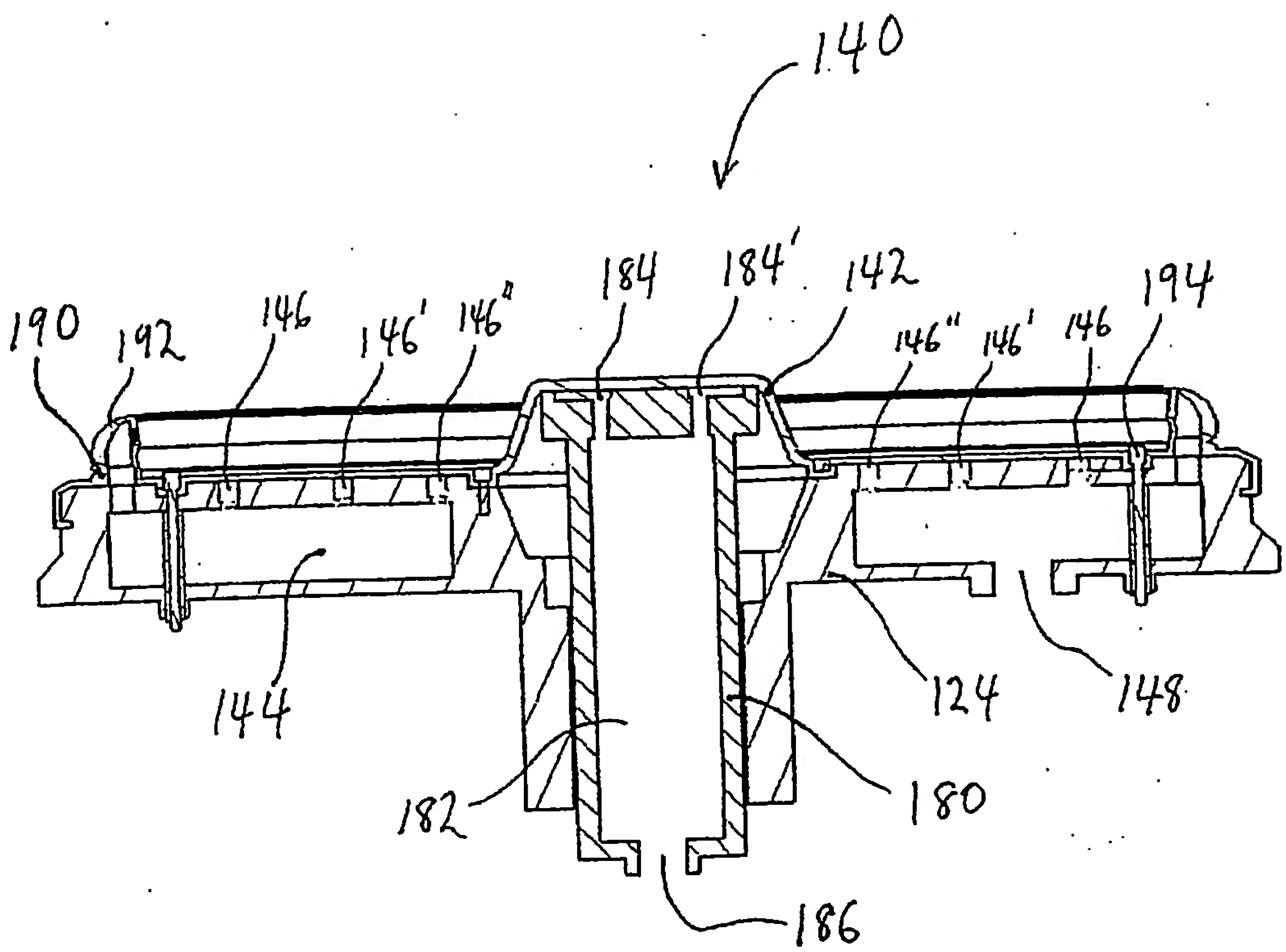
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Fig. 9

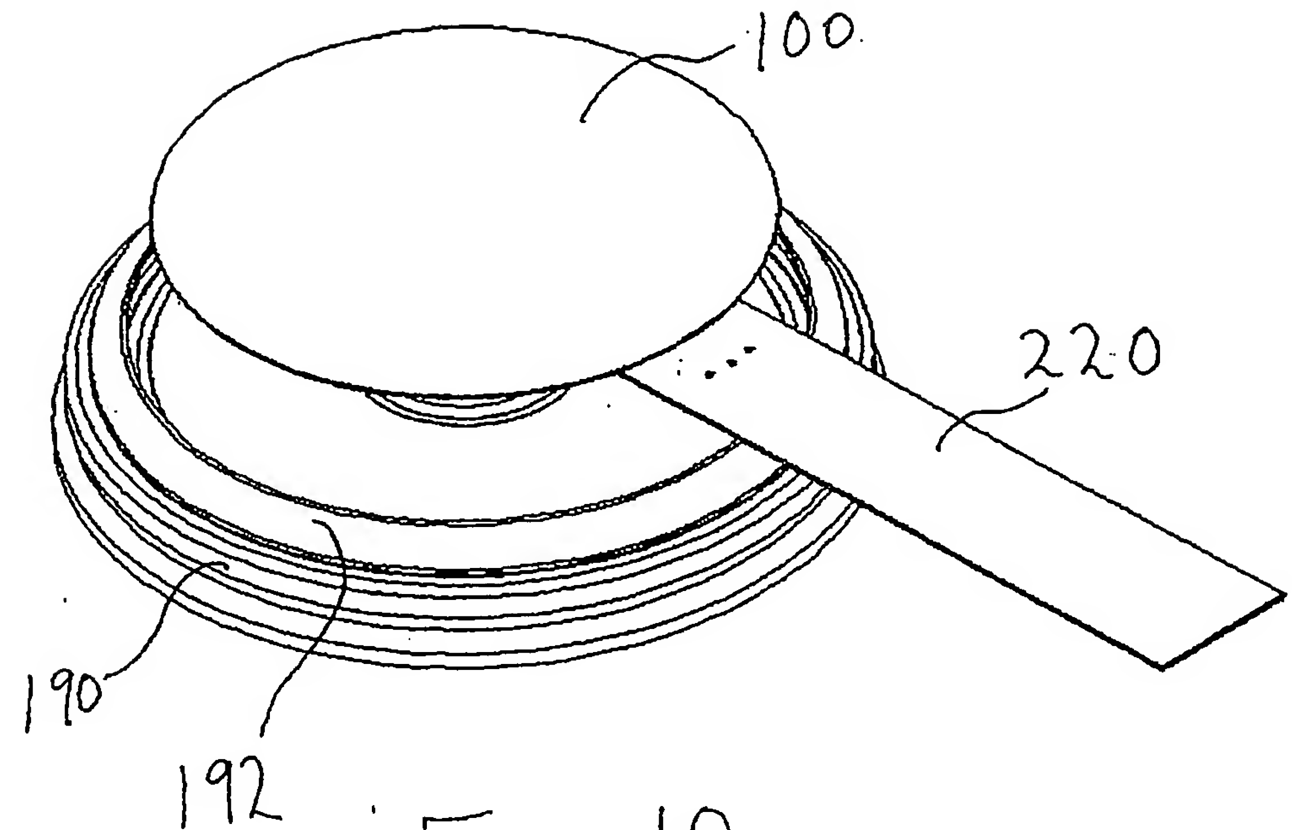

Fig. 10

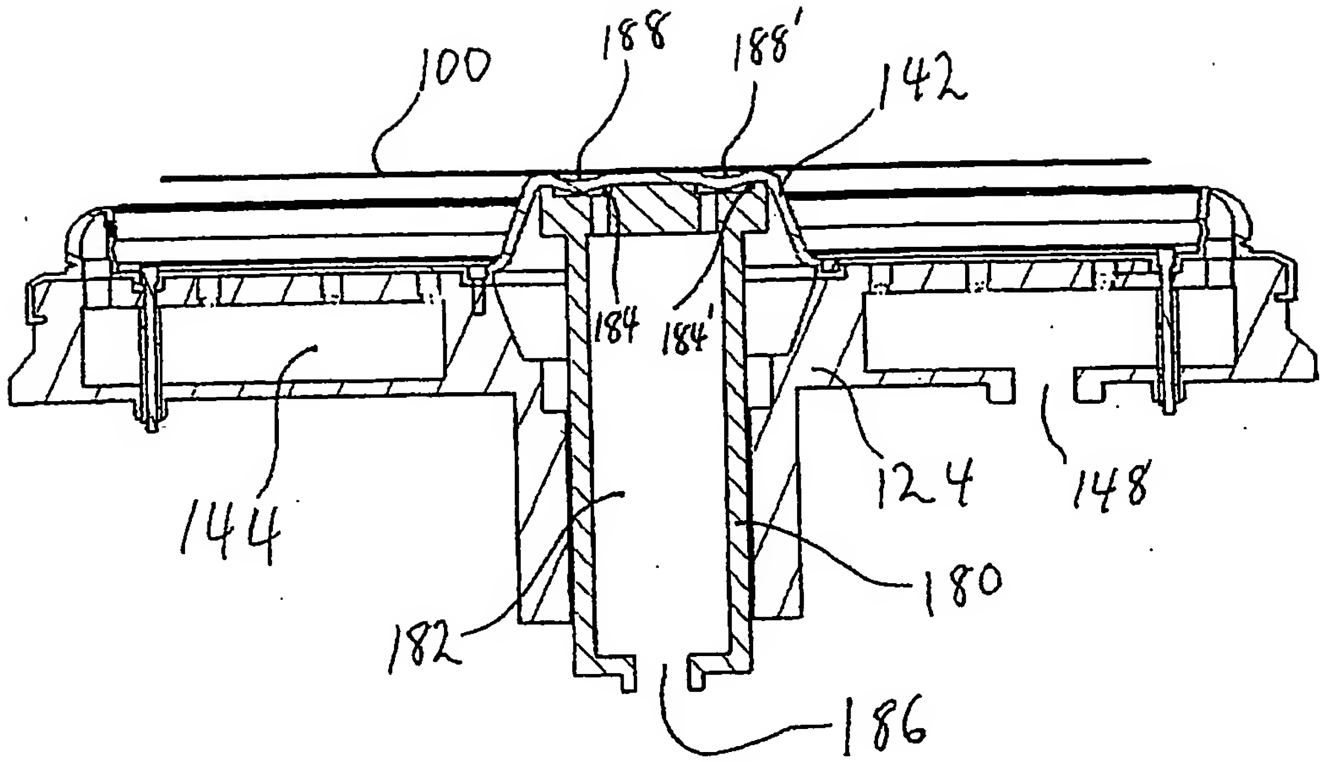

Fig. 11

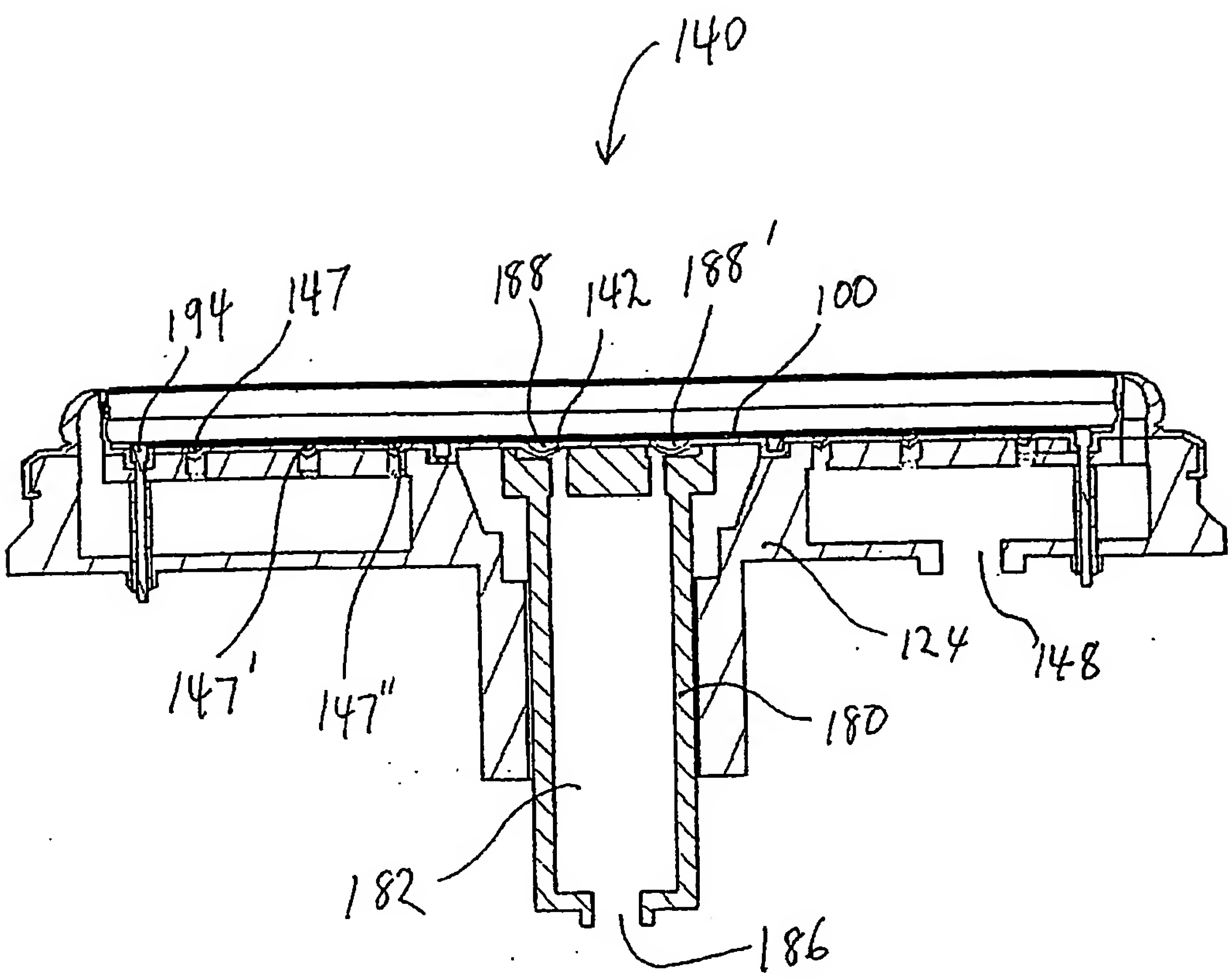

Fig. 12

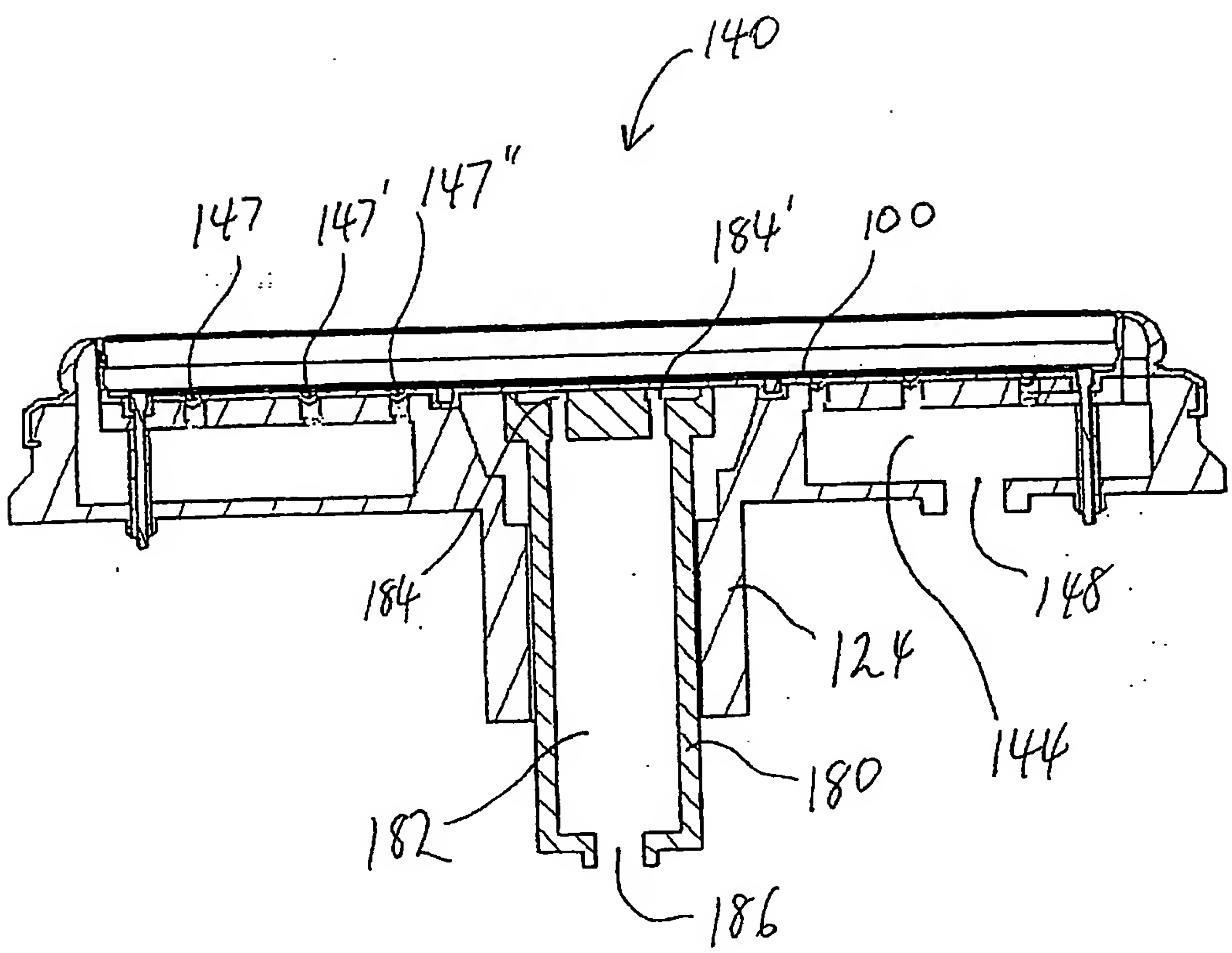

Fig. 13

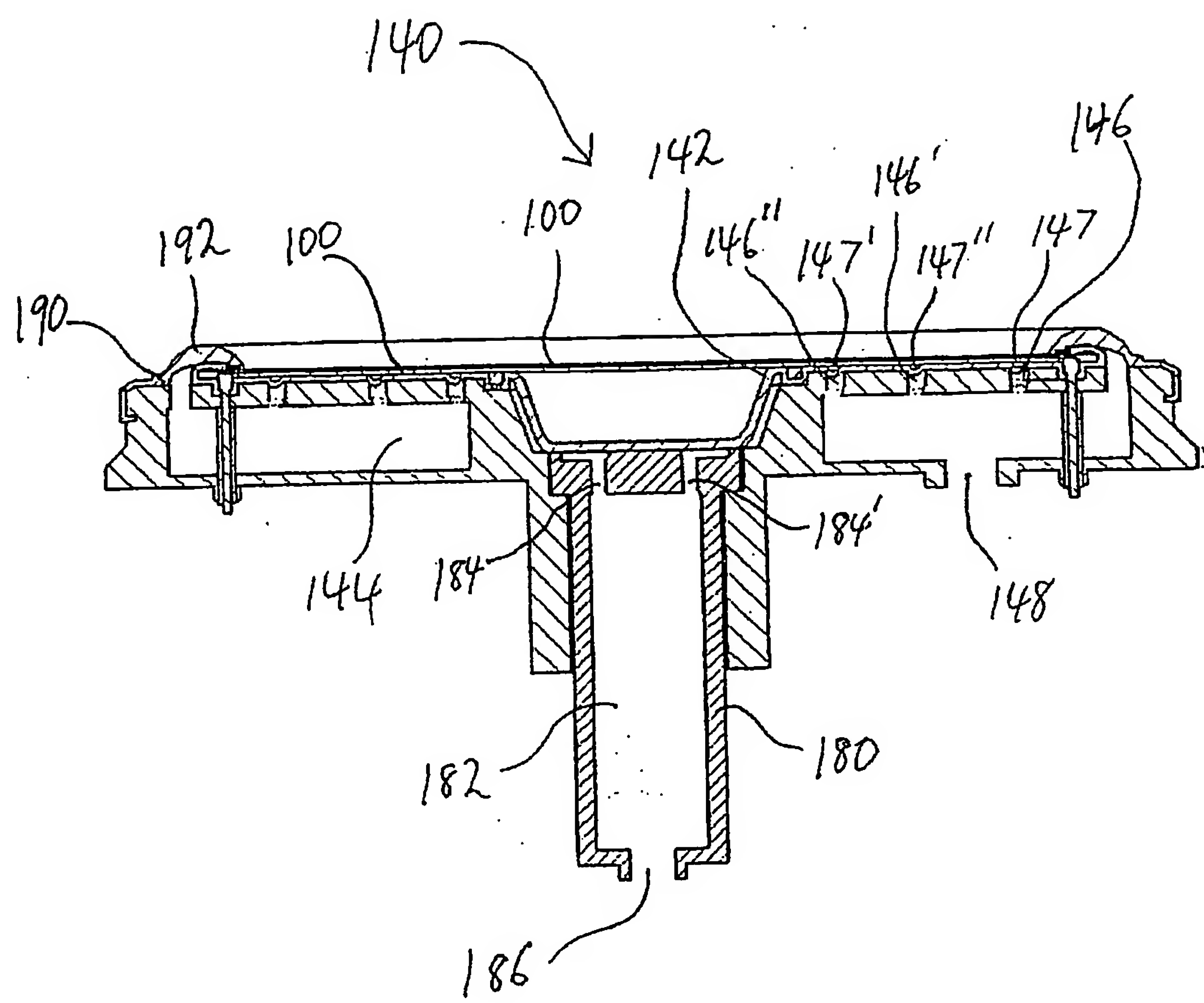
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Fig. 14

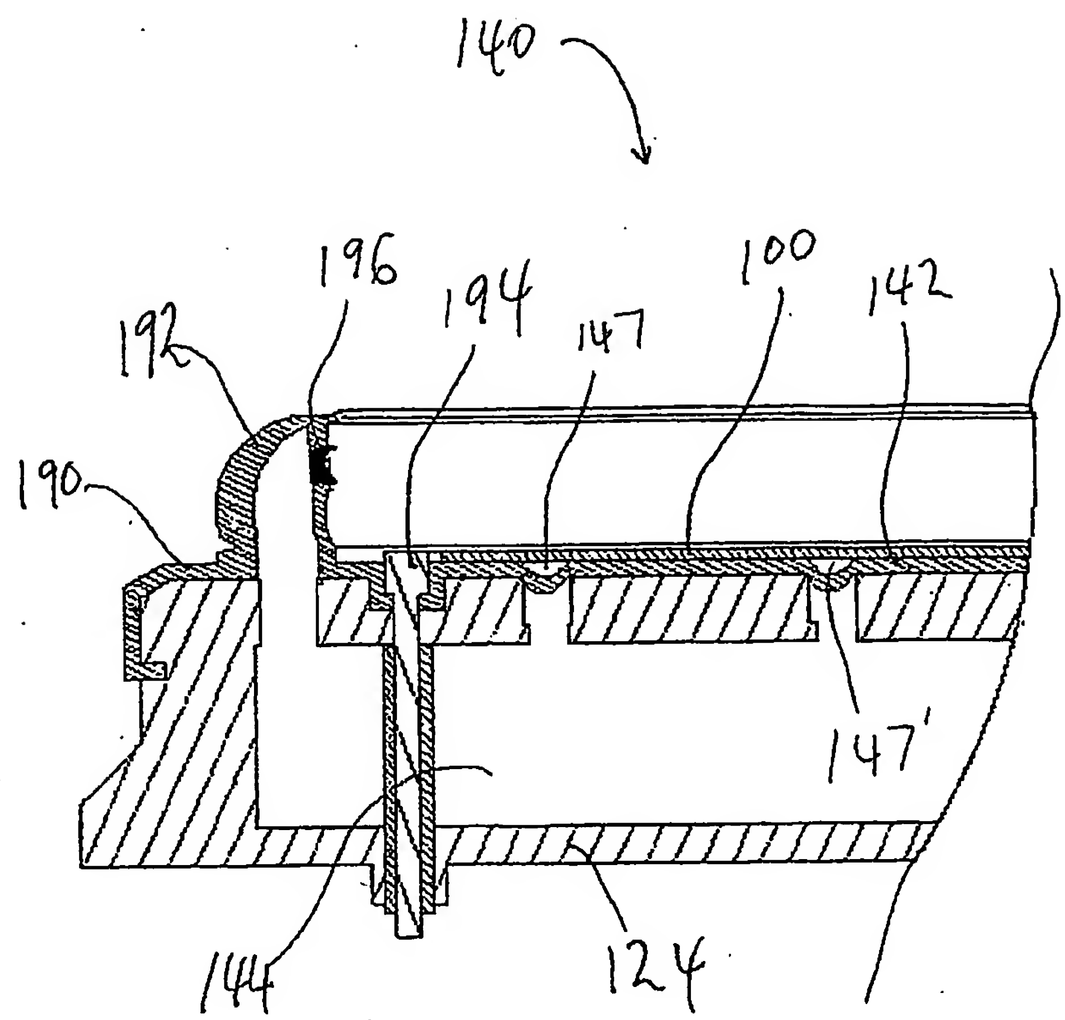

Fig. 15

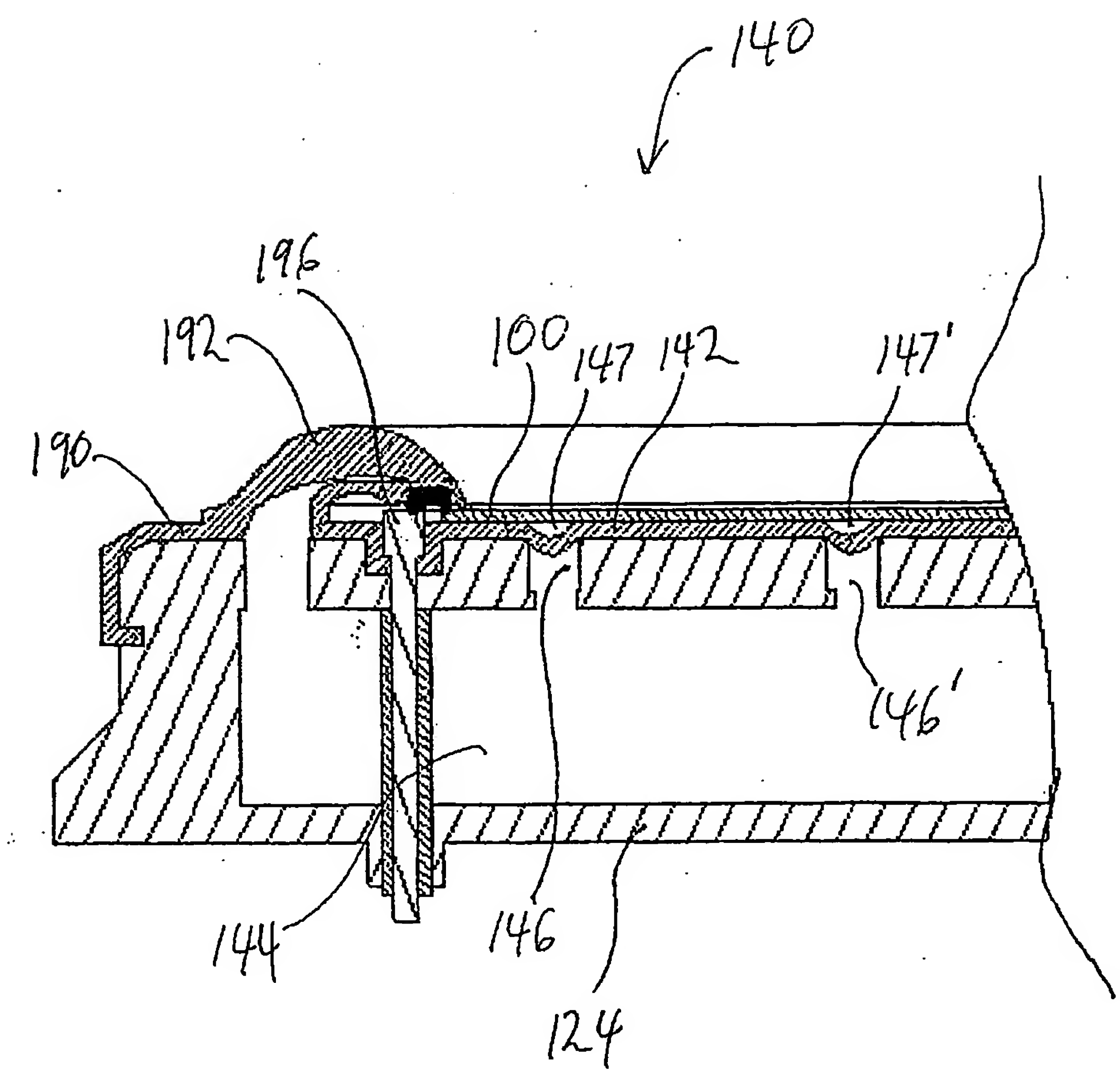

Fig. 16